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Optimizing Performance: The Impact of a 10-Day High-Intensity Interval Training Protocol on Youth Athletic Performance

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Abstract

Objectives. This study aimed to examine the impact of a 10-day High-Intensity Interval Training (HIIT) protocol on the specific endurance of U16 female basketball players, focusing on improvements in aerobic and anaerobic capacity and performance in the Yo-Yo Intermittent Recovery Test Level 1 (YoYoRL1).

Materials and methods. Eight female U16 basketball players participated in the study, completing a 10-day HIIT program designed to enhance both general and sport-specific endurance. Pre- and post-training assessments included body composition measures (weight, BMI, body fat percentage) and the YoYoRL1 test to evaluate changes in performance. The training program incorporated various HIIT modalities, including full-body exercises, parkour circuits, and basketball-specific drills, with progressively adjusted work-to-rest ratios.

Results. The findings showed a substantial improvement in YoYoRL1 test performance from pre-test to post-test, with participants' mean scores increasing from 14.2 ± 1.2 in the pre-test to 16.5 ± 1.2 in the post-test ($p = .001$, $\eta_p^2 = .837$), highlighting a large effect size and strong statistical significance in the results. Body composition analysis revealed a slight increase in weight (64.3 ± 10.6 kg post-test) and a small reduction in body fat percentage (20.2 ± 4.1 % post-test), indicating favorable adaptations in muscle mass and fat distribution.

Conclusions. Implementing the 10-day HIIT protocol significantly improved specific endurance and aerobic capacity in U16 female basketball players, suggesting that short-term HIIT interventions can effectively enhance performance in youth athletes. These findings support the use of HIIT for optimizing endurance and recovery in basketball, with implications for developing time-efficient training protocols for young athletes. However, the study's small sample size and short duration limit the generalizability of these findings, necessitating further research with larger cohorts. Future research should focus on exploring such training program's long-term effects and applicability in various athletic populations.

Keywords: HIIT, Yo-Yo intermittent recovery test, endurance, female basketball, youth athletes.

Introduction

Basketball is characterized by short bursts of intense activity, often repeated at high frequencies throughout a game (Gottlieb et al., 2021). These unique physical demands require athletes to demonstrate mixed (complex) manifestations of aerobic and anaerobic abilities, enabling them to sustain high-intensity efforts and recover quickly between actions (Gottlieb et al., 2014). Research has shown that higher

aerobic capacity is critical role in enhancing a player's ability to perform these intermittent efforts throughout a game and during training sessions (Gottlieb et al., 2021). Effective endurance allows players to recover more rapidly, ensuring they maintain performance levels during games and practices (Liu et al., 2024). Therefore, improving aerobic fitness is essential for optimizing basketball performance.

High-intensity Interval training (HIIT) involves repeated bouts of intense exercise, alternating with recovery periods of lighter activity or rest (Coates et al., 2023). Since a perceived lack of time is a major barrier to widespread

participation in exercise programs, HIIT training is appealing because it offers a potentially more time-efficient way to achieve the adaptive benefits of exercise (Foster et al., 2015). When applied to athletes, HIIT induces physiological adaptations that enhance their ability to sustain high work intensities and resist fatigue during competition (Hung et al., 2025). Unlike traditional endurance training, which requires prolonged sessions, HIIT achieves similar or superior results in a shorter timeframe, making it a more practical option for young athletes with limited training time.

Interval training can be categorized based balancing between aerobic and anaerobic energy contributions. The intensity of the intervals, ranging from submaximal to all-out efforts, determines whether the workout emphasizes aerobic or anaerobic systems (Rosenblat et al., 2020). This differentiation allows for more specific targeting of physiological adaptations, with aerobic HIIT focusing on endurance and anaerobic HIIT enhancing power and speed (Jamnick et al., 2020).

HIIT elicits a range of physiological adaptations that enhance aerobic and anaerobic performance, closely aligning with basketball demands (Shamim, 2021; Tabata et al., 1996). Studies have shown that HIIT significantly improves cardiovascular endurance, power, change of direction ability, and sprint performance in basketball players (Shudian et al., 2025). Cardiovascular adaptations, such as enhanced cardiac contractility and capillary density, increase stroke volume, improving oxygen delivery and VO_2 max. Research indicates that HIIT can increase in stroke volume due to enhanced cardiac contractility and capillary density, contributing to improved aerobic fitness (Irawati & Boenyamin, 2019). Muscular adaptations include increased mitochondrial density (Chr  is et al., 2020). Metabolic improvements, such as enhanced insulin sensitivity, glycogen storage and lactate clearance, increase energy efficiency and fatigue resistance (Zheng et al., 2020; Xie et al., 2024). These adaptations make HIIT an effective, time-efficient training method for basketball players, supporting their ability to sustain high-intensity efforts and recover rapidly.

Sport-specific endurance training in basketball prepares the body's energy systems to efficiently handle the high-intensity actions required during a game. By mimicking basketball demands, HIIT enhances the aerobic system's capacity for recovery and the anaerobic system's ability to deliver quick bursts of energy (Edwards et al., 2018). This targeted approach improves overall endurance and develops stamina and fatigue resistance, which are crucial for maintaining peak performance throughout a basketball match's fast-paced and dynamic.

The Yo-Yo Intermittent Recovery Test Level 1 was developed to evaluate an athlete's ability to repeatedly perform high-intensity aerobic work and has become one of the most popular field tests for youth and recreational athletes (Schmitz, 2018; Bangsbo et al., 2008). It validates and reliably predicts high-intensity aerobic capacity and VO_2 max across various sports and competition levels. It is an essential tool for coaches and trainers assessing endurance and performance potential (Schmitz, 2018; Bangsbo et al., 2008).

HIIT stands as the most renowned method for exceeding the fatigue threshold, however the risks associated with high intensity training lead to a hesitation among coaches

and athletes regarding its implementation. There is a lack of evidence and data on specific standards and protocols designed for specific athlete categories. These points present the need for literature focused on HIIT protocols developed with specific athlete populations in mind.

On the other hand, youth athletes often face time constraints due to academic and extracurricular commitments, limiting the availability of extended training periods (Vacher et al., 2022). Short-term, high-intensity interventions, such as the 10-day HIIT protocol, offer a practical solution by delivering significant fitness improvements within limited timeframes (Atakan et al., 2021). Despite growing interest in optimizing athletic performance, female athletes, remain underrepresented in sports science research, especially basketball. Addressing this gap is critical for developing evidence-based training protocols tailored to their physiological and performance needs.

Against this background, the current study aims to determine the impact of a 10-day HIIT protocol on both aerobic and anaerobic capacity of U16 basketball athletes. By examining the effectiveness of this training regimen, the study hopes to provide valuable insights into optimizing performance for young athletes in this dynamic sport.

Materials and Methods

Study Participants

The study involved eight female U16 National Team basketball players, selected based on their participation in the national program. The study was conducted by ethical standards and was approved by the Ethics Commission (code: 2014/45) of the University for Business and Technology (UBT). The participants had a mean height of 172.9 ± 10.4 cm and a mean weight of 63.2 ± 10.8 kg. This group represents a competitive level of young athletes, providing valuable insights into the effects of the 10-day HIIT protocol on specific endurance in this group. All participants had at least two years of structured basketball training. Still, none had undergone a structured HIIT intervention before the study, ensuring that improvements were attributable to the protocol rather than prior familiarity. Since the group consists of high-level athletes in a specific sport, the number of participants is limited. However, to evaluate the effect size of the sample within the broader population, a G*Power analysis was conducted. The results are presented in Figure 1, with a detailed methodology explanation in the Statistical Analysis section below.

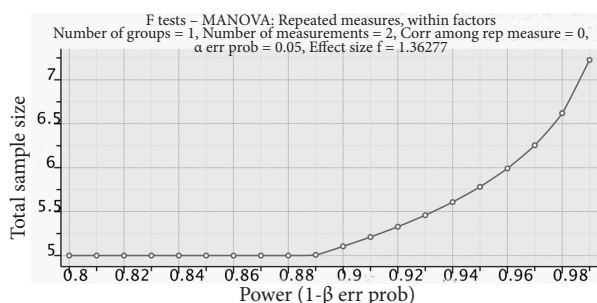


Fig. 1. Effect size of sample size on a targeted population (U16 National Team Basketball Players)

Table 1. Training Protocol Description

Day	Type	Features	Description	Work-rest	Total time	Energy system
1	HIT	Parkour with weight	The parkour consists of five stations. The first station includes Turkish get-ups, followed by lateral and forward swings at the second station. The third station features kettlebell windmills, while the fourth station involves throwing a medicine ball against the wall from both frontal and lateral positions. The final station focuses on backward and sideward ball dribbling with resistance bands for added pressure.	3:1	5×6	Aerobic
2	HIT	Bands, medicine ball	First round: The workout consists of partner exercises using a resistance band. One player holds the band and pulls with one hand while passing a medicine ball to the partner in front. This is done alternately with the left and right hands. The distance between players is determined by the length of the band. This round lasted 15 minutes, including rest breaks. The work-to-rest ratio, as shown in the following row, represents a standard method for structuring exercise and recovery intervals. For example, a 2:1 ratio indicates 20 seconds of work followed by 10 seconds of rest, while a 1:2 ratio corresponds to 10 seconds of work followed by 20 seconds of rest. Second round: The players work in pairs, facing each other, and throw the medicine ball in various ways, such as a two-handed chest pass, followed by alternating left- and right-handed passes. The distance between players is 3 ± 0.50 meters. This round also lasted 15 minutes, including rest breaks.	3:1 4:1 5:1 2:1 1:2 1:3		Aerobic Anaerobic
3	HIIT	Initiating the training a parkour with weight stations, and basketball dribbling	The parkour consists of seven stations, laid out around the basketball court. The first station involves skipping on stairs. The second station features forward jumps over low barriers, while the third station involves side jumps over low barriers. The fourth station includes passing over high barriers, requiring a wide range of motion in the lower body. The fifth station focuses on ball dribbling followed by shooting. The sixth station involves burpees, and the final station is a vertical medicine ball throw.	2:1 3:1 4:1 5:1 4:1 3:1	37	Aerobic Anaerobic
4	HIIT	Parkour with weight stations, and basketball dribbling	The parkour consists of seven stations, laid out around the basketball court. The first station involves skipping on stairs. The second station includes forward and side jumps over low barriers. The third station consists of side jumps over low barriers carrying the medicine ball. Fourth station involves passing over high barriers, requiring a wide range of motion in the lower body. The fifth station includes ball dribbling followed by shooting. The sixth station focuses on burpees, and the final station involves a vertical medicine ball throw.	2:1 3:1 4:1 5:1 4:1 3:1 2:1 1:1	35	Aerobic Anaerobic
5	HIIT	Competitive parkour with weight, runs, jumps and basketball dribbling	The parkour begins with a 14-meter curved run, followed by a triangle where the athlete changes direction and speed before proceeding to the next station, where ball dribbling begins. The entire parkour session lasts 35 minutes, including rest periods between shuttles. The load increases gradually, and depending on the intensity, athletes complete 13-16 rounds across the field. After the first three unloaded (no-weight) rounds, the athlete performs a 10-second skip in place with band resistance before resuming running. Following the fifth round, the athlete carries a 6 kg kettlebell during the initial running line. After the eighth round, the athlete jumps at every corner of the triangle (for agility) following the curved run. After the tenth round, the athletes complete a round without any weight.	1:2 1:3 1:4 1:5 1:1 2:1 3:1 4:1 5:1 1:3 1:4 1:5	35	Anaerobic
6	Tabata	Free or body weight exercises	Four Tabata songs (pre-recorded audio tracks with interval cues) are applied, with each song consisting of 8 work rounds. For each song, four movements are selected, meaning each movement is repeated twice during the 8 rounds. The first song focuses on dynamic, force-based cardiovascular load, with exercises including high skips, alternating leg raises forward and sideward, and burpees. The second song targets local endurance, incorporating bicycle sit-ups, crunches, skipping in a push-up position, and jumping in a push-up position. The third song emphasizes running-based cardiovascular load, where athletes perform side runs, forward-backward runs, side-forward-backward runs (all within 2 meters), and shuttle runs over a 3-meter distance. Finally, the fourth song centers on plyometrics, featuring jumps in place, side jumps, forward-backward jumps, basketball jumping technique, and various other jumps.	2:1	4×5	Anaerobic

Table 1 (continued)

Day	Type	Features	Description	Work-rest	Total time	Energy system
7	Tempo	Fartlek, acceleration, deceleration, Plyometrics	The tempo run consist of five linear lines to be covered by players in three rounds. First round; eight repetitions have been realized such as: first line (4m) max speed run, second line (2m) walk, third line (7m) max speed run, fourth line (2m) walk and the last line (5m) again max speed run. Second round; six repetitions have been realized such as: first line (4m) max speed run and jump, second line (2m) walk, third line (7m) max speed run backwards, fourth line (2m) walk and the last line (5m) max speed run. Third round; five repetitions have been realized such as: first line (4m) max speed run backward and jump, second line (2m) backward walk, third line (7m) max speed run backward and jump, fourth line (2m) walk and the last line (5m) jump and max speed run.	1:1 1:2 1:3 1:4 1:5	30	Anaerobic
8	Tabata	Runs	Four Tabata songs (pre-recorded audio tracks with interval cues) are applied, with each song consisting of 8 work rounds. For each song, four running techniques are determined. The first song focuses on shuttle runs, the second on forward-backward runs, the third on sideward runs, and the fourth on forward-backward-sideward runs.	2:1	4×5	Anaerobic
9	Tabata	Runs	Four Tabata songs (pre-recorded audio tracks with interval cues) are utilized, with each song consisting of 8 work rounds. For each song, four running techniques are designated. The first song focuses on shuttle runs, the second on forward-backward runs, the third on sideward runs, and the fourth on forward-backward-sideward runs.	2:1	4×5	Anaerobic
10	HIIT	Fast break	The players run the length of the entire field in groups of three. One player, positioned in the middle, passes the ball to the players on his right and left, who are running parallel to him. This exercise is repeated three times, after which the players change roles. In the next activity, the two players on the right and left hold the ball and pass it to the player in the middle, who continues running parallel to them. This is also repeated three times, with players changing roles afterward. These two types of drills are conducted over the distance of the field, with the players covering the field 1, 2, and then 3 times without stopping. The specific work-rest ratio for these activities can be found in the adjacent column.	1:1 1:2 1:3 1:4 1:5 1:6	35	Anaerobic

Data collection in this study was conducted following the Declaration of Helsinki and received approval from the University Ethics Committee.

Training Protocol

The HIIT training program was designed to enhance general and sport-specific endurance in basketball players, with a progressively adjusted training load implemented each daily. The program focused on developing general endurance through full-body exercises performed at 75-85% of maximal intensity. In the initial phase, work intervals predominated, with work-to-rest ratios ranging from 3:1 to 5:1. As the program advanced, the balance between work and rest became more equitable, with ratios shifting to approximately 2:1, 1:1, or 1:2.

Once full-body endurance was established, the intensity increased, and the work-to-rest ratios adjusted to approximately 1:3, 1:4, 1:5, or 1:6. This structured progression prepared athletes for the specific endurance demands of basketball, which involve repeated explosive sprints, high jumps, physical confrontations, and rapid transitions between offense and defense.

The training structure combined High-Intensity Training (HIT) to develop strength, HIIT for endurance, Tabata workouts to improve metabolic conditioning, and Tempo runs for speed and agility. This combination provided a comprehensive approach to enhancing aerobic capacity, anaerobic power, and basketball-specific skills. Parkour circuits with resistance exercises (e.g., kettlebell windmills, medicine ball throws) focused on dynamic strength and coordination, while partnered resistance band drills and competitive parkour routines simulated game conditions. Tabata sessions improved cardiovascular endurance and core strength, and tempo runs targeted acceleration, deceleration, and plyometric performance. Each session's work-to-rest ratios evolved from higher work intervals (e.g., 3:1) to ratios emphasizing recovery (e.g., 1:5), ensuring athletes adapted to increasing workloads while preparing for the intermittent nature of basketball gameplay.

Fast-break drills and court-length sprints with ball-passing exercises further emphasized teamwork and game-specific endurance under fatigue. This integration of diverse training modalities addressed basketball's physical and technical requirements, enabling athletes to sustain performance and recover rapidly during competition.

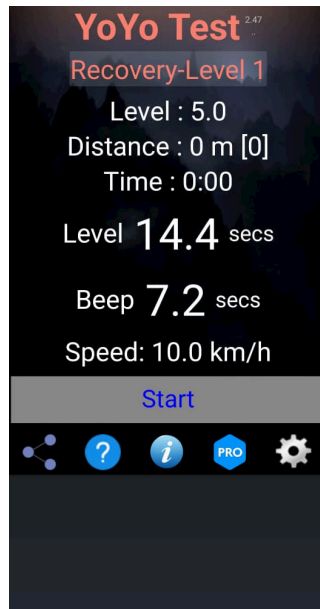


Fig. 2. Yo-Yo Test Settings

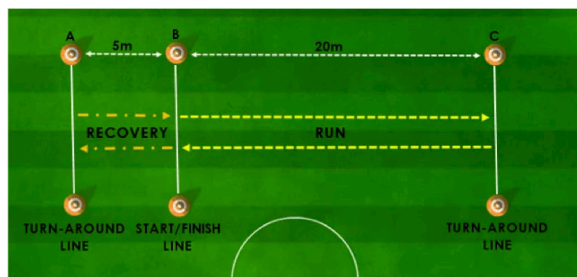


Fig. 3. Yo-Yo Recovery Test Level 1 stage

Table 1 displays the structure and key features of the 10-day HIIT training program implemented in the study.

Yo-Yo Recovery Test Level 1: The Yo-Yo Intermittent Recovery Test Level 1 (YoYoRL1) was administered to participants before and after the training camp to evaluate the impact of the HIIT protocol on their specific endurance.

In the YoYoRL1, participants begin from cone B and must sprint to cone C, reaching it before the subsequent beep. Afterward, they immediately return to cone B before the next signal. Upon reaching cone B, participants have a 10-second recovery period during which they jog to cone A and back to cone B. Participants are allowed two consecutive failed attempts, and a second failure results in elimination from the test. The level achieved is determined based on the number of completed shuttles, which is multiplied by 40 meters to calculate the total distance covered. The standardized table is used to correlate the number of shuttles completed to specific performance levels (Science for Sport, 2025). The YoYoRL1 typically lasts between 5 and 15 minutes (Science for Sport, 2025; Bangsbo et al., 2008). More details can be seen in the figure 2 and 3.

Statistical Analysis

In this study, several statistical methods were employed to analyze the data. The Shapiro-Wilk test indicated that

the data were normally distributed ($p > 0.05$); therefore, parametric tests were employed in this study. Descriptive statistics, including the minimum, maximum, mean, and standard deviation, were calculated for body composition metrics (weight, body mass index, and body fat percentage), as well as for pre-test and post-test scores. These metrics provided an overview of the participants' characteristics and the changes observed before and after the training protocol. To assess the significance of differences between pre-test and post-test scores, a One-Way Repeated Measures Analysis of Variance (ANOVA) was performed. This test was used to determine whether there were significant changes in the Yo-Yo Intermittent Recovery Test Level 1 (YoYoRL1) scores following the 10-day intensive training protocol. The results of the ANOVA indicated a statistically significant difference ($F = 36.044$, $p = 0.001$), with a large effect size (Partial Eta Squared = 0.837), confirming that the protocol had a meaningful impact on Yo-Yo Recovery Test performance. All statistical analyses were conducted at the 0.05 significance level.

Based on the study model, which follows an experimental design with a single control group, the sample size was calculated using the G*Power 3.1.9.4 program. The analysis type A priori: Compute required sample size – given alpha, power, and effect size were applied. From the F tests group, the MANOVA: Repeated Measures, within factors method was selected. The effect size of HIIT training on general and sport-specific endurance, as measured by the Yo-Yo Recovery Level 1 test, was determined based on existing literature. Previous studies indicate a large effect size of HIIT on Yo-Yo Recovery Level 1, with an eta squared statistic of 0.61 (Yuan et al., 2024). This classification is further supported by the National Strength and Conditioning Association, which categorizes an eta squared value of 0.65 as moderate to large (McGuigan et al., 2017).

The input parameters for the analysis were as follows: Effect size f (1.36), α error probability (0.05), Power ($1 - \beta$ error probability) (0.99), Number of groups (1), and Number of measurements (2). As shown in Graph 1, the total sample size of the study (8) achieved a statistical power of 0.99, indicating a high level of reliability.

Results

Table 2 shows significant differences in body composition variables between pre- and post-test conditions, with increases observed in weight ($p = .039$, $\eta_p^2 = .478$) and BMI ($p = .025$, $\eta_p^2 = .538$), indicating moderate to large effect sizes. However, changes in body fat percentage were not statistically significant ($p = .329$, $\eta_p^2 = .136$), suggesting that the observed weight gain resulted from increased glycogen storage and temporary muscle water retention rather than fat accumulation. This is a common short-term physiological response to intensified training.

The table shows a significant improvement in YoYoRL1 test performance from pre-test to post-test, with a mean difference of 2.3 ($p = .001$, $\eta_p^2 = .837$), highlighting a large effect size and strong statistical significance in the results. Although there are no statistically significant correlations ($p > 0.05$), the tendency toward a positive correlation between pre-test and post-test results suggests that athletes who performed better in the pre-test generally maintained their

Table 2. Body Composition Descriptives

Variables	Test time	Min	Max	$\bar{x} \pm S$	$\bar{x}$ diff	F	Sig	η_p^2
Weight (kg)	Pre	45.6	78.9	63.2 ± 10.8	1.1	6.411	.039	.478
	Post	47.4	79.3	64.3 ± 10.6				
Body Mass Index (kg/m ²)	Pre	17.6	24.8	20.9 ± 1.9	0.5	8.153	.025	.538
	Post	18.3	25.1	21.4 ± 1.9				
Body Fat (%)	Pre	13.7	27.7	20.8 ± 5.1	-0.6	1.099	.329	.136
	Post	13.0	26.2	20.2 ± 4.1				

Greenhouse-Geisser: 1.000. The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.

Table 3. One-Way Repeated Measures ANOVA

Test	Factors	Min	Max	$\bar{x} \pm S$	$\bar{x}$ diff	F	Sig	η_p^2	Correlations	
									R	P
YoYoL1	Pre-test	12.0	15.4	14.2 ± 1.23	2.3*	36.044	.001	.837	.577	.134
	Post-test	14.5	17.8	16.5 ± 1.17						

Greenhouse-Geisser: 1.000. The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.

Table 4. Correlations between YoYoL1 test and body composition features

Tests	Sig	Weight		BMI		Fat Percentage	
		Pre	Post	Pre	Post	Pre	Post
YoYoL1	Pre-Test	R	-.733*	-.793*	-.552	-.628	-.654
		P	.038	.019	.156	.095	.079
	Post-Test	R	-.723*	-.732*	-.460	-.439	-.570
		P	.043	.039	.252	.276	.140

relative performance in the post-test, indicating consistency in performance development across both assessments.

The table shows a significant negative correlation between weight and YoYoRL1 scores in pre- and post-test conditions ($p < 0.05$), indicating that higher body weight is related to lower performance. While BMI and fat percentage, as components of body composition related to weight, also show negative correlations with YoYoRL1 scores, these relationships are not statistically significant ($p > 0.05$), suggesting that weight may have a more direct or pronounced effect on performance than its derived measures. Notably, the correlation rates remain consistent between the pre- and post-test results, even with significant changes in body composition and YoYoRL1 performance.

Discussion

This study aimed to evaluate the effects of a 10-day High-Intensity Interval Training (HIIT) protocol on the specific endurance of U16 female basketball players. The results indicated that the protocol effectively improved the participants' specific endurance, as evidenced by significant improvements in the Yo-Yo Intermittent Recovery Test Level 1 (YoYoRL1) scores.

Before the training, participants demonstrated a pre-test YoYoRL1 score of 14.2 ± 1.2 , which increased to 16.5 ± 1.2 after the 10-day concentrated training protocol. This improvement was statistically significant ($F = 36.044$, $p = 0.001$) with a large effect size (Partial Eta Squared = 0.837), suggesting

that the HIIT program enhanced the participants' ability to perform intermittent high-intensity efforts. The increase in YoYoRL1 scores aligns with previous research indicating that HIIT improves aerobic and anaerobic capacity, which are essential for the repetitive high-intensity demands of basketball (Shamim, 2021; Tabata et al., 1996).

The slight increases in weight and body mass index (BMI) and a minor reduction in body fat percentage, observed in this study may indicate short-term physiological responses to intensified training. Expectations include increased glycogen storage and temporary muscle swelling, rather than substantial muscle hypertrophy, which generally requires longer resistance training (Murray & Rosenbloom, 2018; Krzysztofik et al., 2019). Enhanced muscle glycogen storage is a well-documented response to endurance training, improving energy availability during exercise (Murray & Rosenbloom, 2018). This adaptation is particularly beneficial in basketball, where repeated sprints and rapid direction changes require immediate energy replenishment, delaying the onset of fatigue and sustaining performance across multiple quarters. Additionally, although substantial muscle hypertrophy is unlikely in just 10 days, neuromuscular adaptations and temporary muscle water retention may contribute to small increases in body mass (Murray & Rosenbloom, 2018; Uniqgene, 2025). These possible changes could positively influence the athletes' body weight-to-performance ratio, a critical factor in maximizing performance, as a favorable ratio allows athletes to generate more power relative to their body weight, improving their

efficiency in explosive movements like sprints, jumps, and physical confrontations on the basketball court (Simplifaster, 2025).

The observed improvements in specific endurance and body composition further support the relevance of incorporating HIIT into basketball training regimens, especially for youth athletes who face time constraints and require efficient, impactful training protocols. Despite the limited duration of the training program, the participants demonstrated significant gains (see table 3) in endurance, which could translate to improved performance during basketball games, where sustained high-intensity efforts and quick recovery are critical (Edwards et al., 2018). Additionally, a significant negative correlation was found between weight and YoYoRL1 scores in pre- and post-test conditions, suggesting that higher body weight is associated with lower endurance performance. While BMI and fat percentage tended to negatively correlate with YoYoRL1 scores, these relationships were weaker than the correlation with weight. This suggests that total body weight, regardless of composition, may be a more influential factor in endurance performance than fat percentage alone, possibly due to the increased energy demands of carrying additional mass during high-intensity efforts (NSCA, 2017).

This section shows HIIT training was applied with high frequency and intensity. Consequently, this training protocol's effect size on general and sport-specific endurance was substantial. However, despite the high training frequency and intensity, further analysis is needed to enhance the study's accuracy and strengthen its contribution to the existing literature.

Although specific Yo-Yo Intermittent Recovery Level 1 (YoYoRL1) test scores for U16 female basketball players are scarce in the current literature, general normative data for female team sport athletes are available: Elite (>Level 17.5), High level (Level 16.6–17.5), Good (Level 15.6–16.5), Average (Level 14.6–15.5), Below Average (Level 13.1–14.5), and Very Poor (<Level 13.1) (Wood, 2018 ; Bangsbo et al., 2008; Topend Sports, 2025). In our study, participants had a pre-test Yo-Yo IRI score of 14.2 ± 1.2 , which improved to 16.5 ± 1.2 after the 10-day intensive training protocol. Based on the normative data, the participants' initial performance was relatively low. This substantial improvement can be explained by the principle that the lower an athlete's initial motoric level, the easier it is to achieve significant gains. In contrast higher initial levels require greater effort to yield improvements. As a result, the large effect size observed in this study can be attributed to the participants' relatively low starting point.

The present study highlights the importance of sport-specific endurance training, particularly through HIIT, for enhancing basketball performance. By mimicking the intermittent, high-intensity demands of the sport, HIIT optimizes both aerobic and anaerobic systems, helping athletes to better handle the physical stressors of basketball. Moreover, using the Yo-Yo Intermittent Recovery Test Level 1, a reliable field test for aerobic capacity, provides a valuable tool for assessing changes in endurance and guiding training adjustments (Schmitz et al., 2018; Bangsbo et al., 2008). These findings reinforce the importance of incorporating structured HIIT programs into basketball training to enhance endurance performance efficiently. However,

future studies should explore long-term adaptations and individualized training responses, particularly in female athletes, to optimize training interventions further.

The novelty of this study lies in several aspects. First, it demonstrates the effectiveness of a short-term intervention, providing meaningful results in just 10 days. Secondly, it offers specific and standardized data for a defined population (U16 female basketball players). Thirdly, the study introduces a structured HIIT protocol that can be adapted to various athletic populations, regardless of differences in body composition or motor abilities, by adjusting the work-to-rest ratio while maintaining consistent training load principles.

Conclusions

This study demonstrates the effectiveness of a 10-day High-Intensity Interval Training (HIIT) protocol in enhancing the specific endurance of U16 female basketball players. The significant improvements in Yo-Yo Intermittent Recovery Test Level 1 (YoYoRL1) scores highlight HIIT's ability to improve aerobic and anaerobic capacity—crucial components of basketball performance. Additionally, slight increases in body weight and BMI, alongside a minor reduction in body fat percentage, suggest short-term physiological adaptations such as increased muscle glycogen storage and transient water retention, potentially enhancing the body weight-to-performance ratio.

A key consideration is that participants had relatively low initial test scores, likely contributing to the large effect size observed. This aligns with the principle that athletes with lower baseline fitness levels tend to experience greater relative improvements, whereas those with higher initial levels show smaller gains.

Moreover, the scarcity of normative data for the YoYoRL1 test in U16 female basketball players underscores the significance of our findings. Establishing normative data in future research would allow for better benchmarking of endurance performance and the refinement of training protocols tailored to female youth athletes. This study provides valuable insights for coaches and the broader research community, helping to bridge this gap and inform future training methodologies.

Limitations

This study has several limitations that should be considered when interpreting the findings. One of the main limitations is the small sample size of eight U16 female basketball players, which restricts the generalizability of the results. A larger, more diverse sample would allow for stronger statistical conclusions and broader applicability. However, as shown in Graph 1, a G*Power analysis indicated that the total sample size ($n = 8$) achieved a statistical power of 0.99, demonstrating high reliability in detecting significant effects.

Additionally, the absence of a control group limits the ability to determine whether the observed improvements were solely due to the HIIT protocol or influenced by external factors such as individual motivation, prior conditioning, or natural performance fluctuations. Future studies should incorporate a control group to enhance the validity of findings and provide a clearer understanding of the true impact of the intervention.

Another limitation is the specificity of the participant group, as all athletes were members of the U16 national basketball team. This homogeneity means that the results may not directly apply to athletes from other age groups, fitness levels, or sports. Moreover, the short duration of the intervention (10 days) provides insights into the immediate effects of HIIT but does not capture potential long-term adaptations or retention of performance improvements. Future research should explore the sustained effects of HIIT over extended periods and assess its impact on muscle hypertrophy, neuromuscular adaptations, and injury prevention. Additionally, studies should compare HIIT's efficacy against other conditioning methods in basketball to determine optimal training strategies for youth athletes.

Lastly, uncontrolled external factors such as individual differences in recovery, sleep, nutrition, and motivation may have influenced the results. While this study provides valuable insights into the potential benefits of a short-term HIIT program for young female basketball players, addressing these limitations in future research—by incorporating larger and more diverse samples, control groups, and long-term assessments—will enhance the reliability and applicability of the findings.

Conflict of interest

There is no potential conflict of interests declared by the authors

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Оптимізація результативності: Вплив 10-денного протоколу високоінтенсивного інтервального тренування на спортивну результативність молоді

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 10 с., 4 табл., 3 рис., 30 джерел.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу 10-денного протоколу високоінтенсивного інтервального тренування (ВІІТ) на специфічну витривалість баскетболісток вікової категорії до 16 років, з акцентом на поліпшення показників аеробної та анаеробної здатності та результативності Йо-Йо тесту переривчастого відновлення рівня 1 (Yo-Yo Intermittent Recovery Test Level 1, YoYoRL1).

Матеріали та методи. У дослідженні взяли участь вісім баскетболісток віком до 16 років, які виконували 10-денну програму ВІІТ, розроблену для підвищення загальної та спортивно-специфічної витривалості. Аналіз показників перед початком і після завершення тренувань включав вимірювання параметрів композиції тіла (вага, ІМТ, відсоток жирової маси тіла) та виконання тесту YoYoRL1 для визначення змін у результатах. Програма тренувань передбачала застосування різних методів ВІІТ, зокрема комплексні вправи для всього тіла, колові тренування з паркуру та спеціалізовані баскетбольні вправи із поступовим коригуванням співвідношення періодів навантаження та відпочинку.

Результати. Результати дослідження показали суттєве покращення результативності тесту YoYoRL1 від передтестового до післятестового етапів, з підвищенням середнього балу учасниць з $14,2 \pm 1,2$ у передтестовому періоді до $16,5 \pm 1,2$ у післятестовому періоді ($p = 0,001$, $\eta_p^2 = 0,837$), підкреслюючи великий розмір ефекту та сильну статистичну значущість результатів. Аналіз композиції тіла виявив незначне збільшення ваги ($64,3 \pm 10,6$ кг на післятестовому етапі) та невелике зменшення відсотка жирової маси тіла ($20,2 \pm 4,1$ % на післятестовому етапі), що вказує на сприятливі зміни в м'язовій масі та розподілі жиру в організмі.

Висновки. Впровадження 10-денного протоколу ВІІТ сприяло значному поліпшенню специфічної витривалості та аеробної здатності у баскетболісток вікової категорії до 16 років, що свідчить про ефективність короткострокових

ВІІТ-інтервенцій щодо підвищення результативності юних спортсменів. Отримані результати підтверджують доцільність використання ВІІТ з метою оптимізації витривалості та відновлення в баскетболі, що має значення для розроблення ефективних за часом тренувальних протоколів для молодих спортсменів. Однак невеликий розмір вибірки та коротка тривалість дослідження обмежують можливість узагальнення зазначених результатів, що вимагає подальших досліджень із залученням більших когорт. Подальші дослідження слід зосередити на вивченні довгострокових ефектів таких тренувальних програм та їх застосовності у різних групах спортсменів.

Ключові слова: ВІІТ, Йо-Йо тест переривчастого відновлення, витривалість, жіночий баскетбол, юні спортсмени.

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The Synergistic Impact of Combined Massage and Stretching During Halftime on Accelerated Recovery in Football: A Quasi-Experimental Study on Lactic Acid Clearance, Pain Reduction, and Flexibility Improvement

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Abstract

Background. Soccer players frequently encounter performance declines early in the second half due to diminished muscle temperature and the accumulation of fatigue indicators, such as lactic acid.

Objectives. This study aimed to examine the efficacy of massage, stretching, and their combination in facilitating physical recovery during a halftime break in a match. It focused on how quickly lactic acid leaves the body, how much it reduces discomfort from exercise, and how it improves flexibility.

Materials and methods. This study employed a quasi-experimental design, involving 36 male soccer players from UNESA FC. These players were divided into four groups: sports massage (SM), muscle stretching (MS), combination (CMS), and control (CON). The participants engaged in maximum treadmill running (90–95% HRmax) followed by designated recovery procedures: SM, MS, CMS, and CON. Before, during, and after the intervention, lactic acid levels (measured with a lactate meter), range of motion (measured with a goniometer), and pain levels (measured with a visual analogue scale) were all checked. Subsequently, these measures underwent statistical analysis comprising paired t-tests, Wilcoxon tests, MANOVA, and Kruskal-Wallis tests.

Results. This study revealed that the CMS group had the most substantial decrease in lactic acid (12.68 ± 2.37 to 5.16 ± 1.04 mmol/L, $p = 0.000$), outperforming the SM, MS, and CON groups ($p < 0.005$). Furthermore, pain reduction scores were also found significant in the CMS (3.44 ± 2.35 to 1.67 ± 1.58) and MS (4.67 ± 1.11 to 1.33 ± 1.00) groups ($p < 0.05$). Similarly, flexibility improvement was superior in CMS (right ROM: $p = 0.007$; left ROM: $p = 0.003$), while CON showed no marked changes. The MANOVA test revealed significant intergroup differences in post-intervention outcomes ($p < 0.05$).

Conclusions. The findings of this study indicate that the combination of stretching and massage during halftime of a football match helps maximise healing by lowering lactic acid, relieving discomfort, and improving flexibility or range of motion. This approach lowers second-half performance drops and injury risks.

Keywords: football, massage, stretching, recovery.

Introduction

A football match consists of two halves of 45 minutes each, separated by a 15-minute break called halftime. The

players use this break to mentally recover, to hydrate, and to receive tactical instructions to be applied in the second half. Additionally, the halftime break allows the players to recover from any injuries they may have sustained. However, during this 15-minute break, the muscle temperature decreases, which can have a negative impact on the players by affecting their performance in the early minutes of the second half

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and making them more prone to injury (Christaras et al., 2023). Moreover, studies show that football players run less and with a lower intensity in the first 10–15 minutes of the second half compared to the same interval in the first half. In a recent study, Russell et al. (2016) reported this issue among the English Premier League players. In the first 15 minutes of the second half, they noted that the number of decelerations, the distance covered at high intensity, and the running speed of the players differed significantly from those in the first half. Other studies have reported that kicking accuracy decreased by 38.02% (Alkhalaf, 2023) and kicking speed decreased by 8.5% (Ferraz et al., 2011). They believed that fatigue experienced by the players was the potential factor of these declines. Other scholars argued that the decline in performance in the first few minutes after the break might be caused by less than optimal recovery in the first half, a lack of preparation for the second half, and other factors such as internal motivation and tactical instructions by the coach (Christaras et al., 2023).

Football is a sport that uses aerobic and anaerobic energy systems, with a greater emphasis on the anaerobic system (Bekris et al., 2016; Turna et al., 2023). Activities that rely on the anaerobic energy system use energy from both the anaerobic glycolysis system and ATP-PCr. These activities are carried out with high intensity in a short time (Kafrawi et al., 2024a). As a result of anaerobic exercise, heart rate and lactic acid levels will rise, delayed onset muscle soreness (DOMS) will happen later, and range of motion (ROM) and malondialdehyde (MDA) levels will drop (Almeida et al., 2019; Awang Daud et al., 2022; Pesenti et al., 2021; Rusdiawan et al., 2020a).

When the DOMS occurs, players feel pain and stiffness, which increases after exercise and causes a decrease in joint range of motion (ROM) (Peake et al., 2017). Additionally, accumulated lactic acid levels cause decreased muscle contraction abilities and fatigue (Sari et al., 2019). When the level increases, the pH will decrease, which causes enzyme performance to become slower. As a result, the ATP formation process is inhibited. This condition typically causes fatigue and hampers an individual to achieve their best performance (Hartono et al., 2019).

Fatigue is a decrease in the ability to maintain physical and mental activity during training or matches. It can occur during high-intensity training or competition due to a tight schedule. Frequently, it is one of the predicting factors of an athlete's decreased performance (Rampinini et al., 2011; Robineau et al., 2012). Thus, it is necessary to prevent the players from experiencing excessive fatigue, and one of the strategies is maximising recovery. Recovery is a process aimed at restoring the body's metabolic function to normal before the activity (Fahmi & Ashadi, 2019). In football, recovery from intensive training or competition is crucial for maintaining athlete performance. Faster recovery leads to greater advantage. This can be reached by neutralising the accumulation of lactic acid. In football, athletes who recover faster from intensive training or competition have a greater advantage (Marqués-Jiménez et al., 2017; Pinar et al., 2012).

Previous studies have widely discussed this topic and examined several methods to speed up recovery, such as muscle stretching and sports massage. Muscle stretching is defined as applying a force to a muscle structure to achieve changes in length in order to increase joint range of motion

(ROM), reduce muscle stiffness or pain, and also prepare for physical activity (Sands et al., 2013). This activity is generally prescribed to increase strength recovery, ROM, and DOMS after physical activity (Afonso et al., 2021). Muscle stretching can neutralise lactic acid, muscle spasms, and muscle pain (Zulaini et al., 2021). Muscle spasms that limit joint range of motion can also be overcome by doing muscle stretching (Zulaini et al., 2021). According to Herbert et al. (2011), there are some stretching models available to sports players, such as the four movements in Anderson's stretching model. However, these movements are unsuitable during a football match break because they require standing. Therefore, the present research proposes a series of ball stretches that can be performed while lying on the back or stomach to enhance player comfort.

Besides stretching, plenty of research offers massage as an alternative therapy because it expedites healing, diminishes pain intensity, and facilitates the restoration of damaged muscles (Kafrawi et al., 2024b). It is also effective in decreasing lactic acid concentrations (Welis et al., 2023) and beneficial when administered for durations of 10, 20, 30, or 60 minutes (Hunt et al., 2019; Piotrowska et al., 2021). Other research indicates that sports massage techniques may diminish lactic acid buildup (Budak, 2023) and enhance recovery by artificially stimulating the venous and lymphatic pump mechanisms, therefore expediting blood circulation (Davis et al., 2020). Massage is also advantageous in enhancing microcirculation, particularly in small blood vessels with diameters under 100 micrometers. It facilitates the transport of oxygen and nutrients to cellular tissues and the removal of metabolic waste. This process aids in eliminating lactic acid from tissues, enabling its diffusion into the bloodstream (Güven et al., 2019). This can happen because the lactic acid in the bloodstream is transported to the liver via the Cori cycle for conversion into glucose (Freire Jorge et al., 2017).

Although this sports massage model is beneficial, its implementation during the match break has some obstacles. For example, the players might feel pain, so the results may be less optimal. For this reason, this research proposes a combination of stretching massage models as an alternative to reduce pain during massage, namely the lower extremity body, with stretching techniques, massage, and stretching again.

Materials and Methods

This study employed a quasi-experiment research method, examining the influence of a variable on another variable through various cause-and-effect scenarios (McDonough, 2017). In this experiment, a "Purposive Randomized Control Group Pretest-Posttest Design" was used. The purpose was to identify changes caused by muscle stretching, sports massage, and the combination of sports massage and muscle stretching. Details of the research design are illustrated in Figure 1.

Study participants

This study involved 36 football players from UNESA FC as the sample. The sample size was determined using the Slovin formula with a 5% margin of error. The samples were then divided into 4 groups of equal size using the simple random sampling method so that each sample had

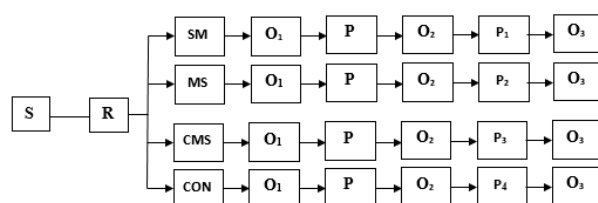


Fig. 1. Research design

Note: S: Research sample. R: Randomisation. SM: Sports Massage group. MS: Muscle Stretching group. CMS: Combination of Sports massage and Stretching group. CON: Control Group (sit down and rest). O1: Pre-test (ROM and lactic acid levels test). O2: Post-test 1 (Exercise pain, ROM and lactic acid levels test). O3: Post-test 2 (Exercise pain, ROM and lactic acid levels test). P: Doing maximum intensity treadmill running (90%-95% HR Maks). P1: Sport massage. P2: Muscle stretching. P3: Combination of Sports Massage and Stretching. P4: No treatment (just sit down and rest)

the same opportunity to enter the group (Firmansyah & Dede, 2022; Ramadhani Khija & Ludovick Uttoh, 2015). After that, the selected samples were given informed consent and signed a willingness to receive treatment as well as tests and measurements of lactic acid, pain, and range of motion (ROM). As the study involved human subjects, it complied with the Declaration of Helsinki. In particular, it has been granted ethical approval by the Universitas Negeri Semarang Health Research Ethics Committee, under reference number 068/KEPK/FK/KLE/2024, which is in line with the Declaration of Helsinki.

Study organisation

As mentioned earlier, this study involved four groups: the Sports Massage (SM), Muscle Stretching (MS), Combination of Sports Massage and Stretching (CMS), and Control (CON) groups. The night before the pretest, the samples were asked to fast but were allowed to drink water as needed. During the pretest, they were requested to come at 07:00 am to undergo a health check. Following the health check, we administered a pretest to each group, collecting data on pain, range of motion, and lactic acid levels. After the pretest, they ran on a treadmill with maximum intensity (90-95% of maximum HR). Five minutes after the treadmill session, the research samples underwent posttest 1, which involved pain, range of motion, and lactic acid level measurements. Next, different treatments were given depending on the sample's group. For example, sports massage treatment was given to the SM group, muscle stretching was given to the MS group, and a combination of both was given to the CMS group for 10 minutes. On the other hand, no treatment was given to the CON group as they served as the control group. Then, the samples were measured again (posttest 2) to check their pain, ROM, and lactic acid levels after the treatment. Table 1 below explains how sports massage, stretching, and a combination of massage and stretching are implemented in this experiment.

Measurement

This study aimed to measure several indicators, such as exercise pain, ROM, and lactic acid levels. When measuring

lactic acid and ROM, the data were collected 3 times: pretest, posttest 1, and posttest 2. Meanwhile, exercise pain examination was only carried out 2 times during posttest 1 and posttest 2. The pretest was carried out before exercise by requesting the research samples to run on a treadmill until their heart rates reached maximum intensity (95%). On the other hand, posttest 1 was carried out after exercise, and posttest 2 was carried out after a sports massage, stretching, or control (without recovery treatment).

After the data collection, lactic acid was quantified via a Roche Cobas Accutrend Plus GCTL Meter. The acid was utilised by extracting blood from the sample fingertips and thereafter applying it to the apparatus (Rusdiawan et al., 2020; Rusdiawan & Habibi, 2020b). To measure pain after running, a visual analog scale was used (Delgado et al., 2018; Han et al., 2011). Meanwhile, ROM was measured using a goniometer on the left and right knee joints expressed in angular units (Shah, 2008) knee flexion and extension range of motion (ROM).

Statistical analysis.

The data were then processed using the Microsoft Office Excel 2016 and SPSS Series 23 programs with a significance level 0.05. It involved several data analyses. First, a descriptive statistical test was used to determine the mean and standard deviation of the dependent variable in each group during the pretest and posttest. After that, a normality test was carried out as a prerequisite to determine the appropriate statistical test. In this study, the data were considered normal if $p > 0.05$. The homogeneity test was also administered to ensure variance between similar groups, with homogeneous criteria if $p > 0.05$. Following that, the paired t-test was performed to test the effect of treatment by comparing pretest and posttest values, where the value is considered significant if $p < 0.05$. Additionally, the Manova test was done to test the mean difference between groups on all variables, where the value is considered significant if $p < 0.05$. Finally, the study employed the Post Hoc test to determine the difference in treatment between groups if the Manova results show a significant difference ($p < 0.05$).

Results

This section outlines whether certain types of massage or stretching can lower pain during massage. To achieve the goal, this study involved 36 football players from UNESA FC with the mean $\pm$ SD of their physical characteristics included age 21.56 ± 1.29 years, weight 64.56 ± 3.85 kg, height 172.79 ± 2.81 cm, and training experience 14.52 ± 2.86 years. The results of these statistics are shown in Table 2.

Table 2 shows that lactic acid levels increased in all groups after high-intensity exercise, followed by a decrease after treatment. The highest decrease in lactic acid levels occurred in the CMS group, with an average change from 12.68 ± 2.37 mmol/L at posttest 1 to 5.16 ± 1.04 mmol/L at posttest 2. In addition, exercise-related pain also decreased in all groups after treatment, with the MS group experiencing the largest decrease, from 4.67 ± 1.11 to 1.33 ± 1.00 . In terms of range of motion (ROM), there was a substantial increase after treatment, especially in the CMS group for the right and left ROM. This increase indicates that the combination

Table 1. Implementation of treatment

Treatment	Procedure
Exercise	The exercise in this study was done by running on a treadmill. The duration of the run was determined by each participant's performance until their heart rate reached 95% of their maximum heart rate.
Sports Massage	Sports massage was given to the lower extremities of the participants. The massage techniques were effleurage, petrissage, shaking, tapotement, and walking. Each technique was performed with six repetitions, with the opening and closing done by effleurage.
Stretching	This stretching was done passively with the assistance of another person. The procedures were described as follows: The assistant's left hand held the upper thigh, and the right hand was attached to the sole of the participant's right foot. Then, it was pushed and held in a count of 1-6, 1-8, and vice versa. The participant's right leg was bent, with the left hand holding the knee and the right hand holding the sole of the participant's foot. The participant pushed with a count of 1-6, 1-8, and vice versa. The participant's right leg was lifted 30° and placed on the assistant's thigh. Then, the left hand pressed the knee down, and the right hand pushed with a count of 1-6, 1-8, and vice versa. The participant's leg was raised by 60°. The left hand pressed the knee, and the right hand held the sole of the foot. Then, it was pushed with a count of 1-6, 1-8, and vice versa. The right leg was lifted 120° with the left hand, and the right hand held the participant's left foot and vice versa. The participant's right leg was raised 90°, clamped with both of the masseur's knees. Additionally, the right arm was placed on the participant's sole and pressed with the addition of the masseur's body weight. This position was held for a count of 1-6, 1-8, and vice versa. Both knees were bent and pushed until they touched the participant's chest. This position was held for a count of 1-6. The left hand held the upper thigh above the knee, and the right arm was attached to the participant's right sole. Then, it was pushed and held for a count of 1-6, 1-8, and vice versa. The participant's right leg was bent, while the left hand held the knee, and the right hand held the participant's sole. They were push for a count of 1-6, 1-8, and vice versa. The participant's right leg was raised 30° and placed on the assistant's thigh. Then, the left hand pressed the knee down, and the right hand pushed for a count of 1-6, 1-8, and vice versa. The player's legs were raised by 60° while the left hand pressed the knee. Then, the right hand held the sole of the foot, then was pushed for a count of 1-6, 1-8, and vice versa. The right leg was lifted 120° with the left hand. The right hand held the player's left leg and vice versa. The participant's right leg was lifted 90° and clamped with both assistant's knees. The right arm was placed on the participant's soles and pressed with the addition of the assistant's body weight held for a count of 1-6, 1-8, and vice versa. Both knees were bent and pushed until they touched the participant's chest. Then, this position was held for a count of 1-6.
Combination of massage and stretching	The procedures of combined massage and stretching are described as follows: Participants were in a supine position, where both legs were raised with the ankle grip and shaken rhythmically up and down. Both legs were pulled up at a 90° angle, while both knees were straightened. The soles of both feet were pushed down with body weight, counting 1-6. After that, release the soles and then push again, counting 1-7, release and push again, and counting 1-8. Both legs are extended with both legs open, stretched to a count of 1-6, released, counted again 1-7, released, and counted again 1-8. Both legs were spread apart and stretched with a count of 1-6 off, a count of 1-7 off, and a count of 1-8. With both knees bent simultaneously, the knees were pushed forward for a count of 1-6, released for a count of 1-7, and then pushed again for a count of 1-8. The front, inner, and outer upper legs were massaged by several techniques, such as effleurage, shaking, and hitting with light pressure. The tempo was quick and finished with more effleurage. The front and back lower legs were massaged by effleurage. Meanwhile, the tibial and the back parts were treated with effleurage, petrissage, shaking, and tapotement, followed by petrissage of the soles of the feet. The player was positioned in a prone position. The upper back was cooled down by effleurage, petrissage, shaking, and tapotement and effleurage. The lower cooling-down massage targeted the gastrocnemius through a combination of effleurage, petrissage, shaking, and rhythmic light strokes. Then, the soles of the feet were massaged with effleurage, petrissage, shaking, and effleurage. Both legs were straightened and extended again with a count of 1-6 and 1-8.

of massage and stretching is effective in restoring muscle flexibility. These results also provide a comprehensive picture of the effect of treatment on the recovery of football players' physical conditions.

After describing the participants' characteristics, a difference test was required before and after treatment

(pretest-posttest). If the variables were normally distributed, a paired t-test was employed. On the other hand, a Wilcoxon test was done for non-normally distributed variables. The objective of this test was to assess the impact of the administered treatments, such as sports massage, stretching, and a combination of massage and stretching, on each group.

Table 2. Descriptive statistics of lactic acid, exercise pain, and ROM

Group		Variable	Mean $\pm$ SD	Min	Max
SM	Lactic Acid	Pretest	5.91 $\pm$ 2.25	3.40	9.60
		Posttest 1	11.79 $\pm$ 2.37	9.30	15.90
		Posttest 2	7.21 $\pm$ 2.87	3.10	12.40
		Δ Pretest - Posttest 1	-5.88 $\pm$ 2.31	-9.20	-2.60
		Δ Pretest - Posttest 2	-1.30 $\pm$ 2.88	-5.20	3.00
		Δ Posttest 1 - Posttest 2	4.58 $\pm$ 1.04	2.80	6.20
MS	Lactic Acid	Pretest	3.23 $\pm$ 2.1	1.50	7.10
		Posttest 1	11.38 $\pm$ 2.35	9.50	16.30
		Posttest 2	6.69 $\pm$ 2.13	4.50	10.50
		Δ Pretest - Posttest 1	-8.14 $\pm$ 2.1	-9.90	-3.10
		Δ Pretest - Posttest 2	-3.45 $\pm$ 2.28	-8.90	-0.50
		Δ Posttest 1 - Posttest 2	4.69 $\pm$ 2.00	0.70	7.60
CMS	Lactic Acid	Pretest	5.50 $\pm$ 1.01	3.30	6.70
		Posttest 1	12.68 $\pm$ 2.37	10.60	17.60
		Posttest 2	5.16 $\pm$ 1.04	4.20	7.40
		Δ Pretest - Posttest 1	-7.18 $\pm$ 2.12	-11.30	-4.70
		Δ Pretest - Posttest 2	0.34 $\pm$ 1.10	-1.10	2.00
		Δ Posttest 1 - Posttest 2	7.52 $\pm$ 1.50	5.30	10.20
CON	Lactic Acid	Pretest	4.26 $\pm$ 2.43	1.40	10.00
		Posttest 1	9.99 $\pm$ 3.40	3.50	14.60
		Posttest 2	8.40 $\pm$ 3.00	3.10	12.60
		Δ Pretest - Posttest 1	-5.73 $\pm$ 2.67	-10.40	-0.60
		Δ Pretest - Posttest 2	-4.14 $\pm$ 2.35	-8.50	-0.20
		Δ Posttest 1 - Posttest 2	1.59 $\pm$ 0.82	0.40	2.60
SM	ROM Dextra	Pretest	112.22 $\pm$ 4.41	105.00	120.00
		Posttest 1	107.78 $\pm$ 2.64	105.00	110.00
		Posttest 2	118.33 $\pm$ 4.33	110.00	125.00
		Δ Pretest - Posttest 1	4.44 $\pm$ 4.64	-5.00	10.00
		Δ Pretest - Posttest 2	-6.11 $\pm$ 4.17	-10.00	0.00
		Δ Posttest 1 - Posttest 2	-10.56 $\pm$ 4.64	-15.00	-5.00
MS	ROM Dextra	Pretest	111.11 $\pm$ 6.51	100.00	120.00
		Posttest 1	104.44 $\pm$ 4.64	100.00	110.00
		Posttest 2	114.44 $\pm$ 4.64	110.00	120.00
		Δ Pretest - Posttest 1	6.67 $\pm$ 6.12	-5.00	15.00
		Δ Pretest - Posttest 2	-3.33 $\pm$ 6.12	-15.00	5.00
		Δ Posttest 1 - Posttest 2	-10.00 $\pm$ 2.50	-15.00	-5.00
CMS	ROM Dextra	Pretest	112.78 $\pm$ 8.33	95.00	120.00
		Posttest 1	107.22 $\pm$ 2.64	105.00	110.00
		Posttest 2	117.22 $\pm$ 2.64	115.00	120.00
		Δ Pretest - Posttest 1	5.56 $\pm$ 8.82	-15.00	15.00
		Δ Pretest - Posttest 2	-4.44 $\pm$ 9.17	-25.00	5.00
		Δ Posttest 1 - Posttest 2	-10.00 $\pm$ 3.54	-15.00	-5.00
CON	ROM Dextra	Pretest	115.00 $\pm$ 4.33	110.00	120.00
		Posttest 1	109.44 $\pm$ 8.82	100.00	125.00

Table 2 (continued)

Group		Variable	Mean $\pm$ SD	Min	Max
		Posttest 2	108.89 $\pm$ 6.01	100.00	120.00
		Δ Pretest - Posttest 1	5.56 $\pm$ 6.82	-5.00	15.00
		Δ Pretest - Posttest 2	6.11 $\pm$ 5.46	0.00	15.00
		Δ Posttest 1 - Posttest 2	0.56 $\pm$ 7.68	-10.00	15.00
SM	ROM Sinistra	Pretest	111.39 $\pm$ 2.20	110.00	115.00
		Posttest 1	108.61 $\pm$ 3.77	105.00	115.00
		Posttest 2	116.67 $\pm$ 5.59	105.00	125.00
		Δ Pretest - Posttest 1	2.78 $\pm$ 2.32	0.000	5.00
		Δ Pretest - Posttest 2	-5.28 $\pm$ 5.65	-15.00	5.00
		Δ Posttest 1 - Posttest 2	-8.06 $\pm$ 5.83	-20.00	0.00
MS	ROM Sinistra	Pretest	110.56 $\pm$ 3.91	105.00	115.00
		Posttest 1	110.56 $\pm$ 7.68	100.00	125.00
		Posttest 2	115.00 $\pm$ 5.59	105.00	120.00
		Δ Pretest - Posttest 1	0.00 $\pm$ 9.68	-20.00	10.00
		Δ Pretest - Posttest 2	-4.44 $\pm$ 7.26	-15.00	5.00
		Δ Posttest 1 - Posttest 2	-4.44 $\pm$ 5.83	-15.00	5.00
CMS	ROM Sinistra	Pretest	113.89 $\pm$ 3.33	110.00	120.00
		Posttest 1	104.44 $\pm$ 5.27	95.00	110.00
		Posttest 2	117.22 $\pm$ 2.64	115.00	120.00
		Δ Pretest - Posttest 1	9.44 $\pm$ 5.27	0.00	15.00
		Δ Pretest - Posttest 2	-3.33 $\pm$ 5.00	-10.00	5.00
		Δ Posttest 1 - Posttest 2	-12.78 $\pm$ 6.18	-25.00	-5.00
CON	ROM Sinistra	Pretest	117.78 $\pm$ 4.41	110.00	125.00
		Posttest 1	108.33 $\pm$ 4.33	100.00	115.00
		Posttest 2	108.33 $\pm$ 6.12	100.00	120.00
		Δ Pretest - Posttest 1	9.44 $\pm$ 5.27	5.00	20.00
		Δ Pretest - Posttest 2	9.44 $\pm$ 4.64	5.00	15.00
		Δ Posttest 1 - Posttest 2	0.00 $\pm$ 6.61	-10.00	10.00
SM	Exercise pain	Posttest 1	2.56 $\pm$ 2.01	0	5
		Posttest 2	0.78 $\pm$ 0.97	0	2
		Δ Posttest 1 - Posttest 2	1.78 $\pm$ 1.64	0	4
MS	Exercise pain	Posttest 1	4.67 $\pm$ 1.11	3	6
		Posttest 2	1.33 $\pm$ 1.00	0	3
		Δ Posttest 1 - Posttest 2	3.33 $\pm$ 1.32	2	5
CMS	Exercise pain	Posttest 1	3.44 $\pm$ 2.35	0	6
		Posttest 2	1.67 $\pm$ 1.58	0	4
		Δ Posttest 1 - Posttest 2	1.78 $\pm$ 1.30	0	4
CON	Exercise pain	Posttest 1	3.89 $\pm$ 2.47	0	7
		Posttest 2	3.56 $\pm$ 2.01	0	6
		Δ Posttest 1 - Posttest 2	0.33 $\pm$ 1.32	-2	2

Note: Δ is the difference

Table 3 below presents the results of the paired t-test and Wilcoxon test for each variable.

Table 3 shows that lactic acid levels in all groups significantly decreased after the intervention, with a p-value < 0.05

in the paired test and Wilcoxon t-test. Among the examined groups, the CMS group was reported to have the most significant decrease between Posttest 1 and Posttest 2, with a p-value of 0.000. This decrease indicates the effectiveness of

Table 3. Effect of maximum running exercise and recovery on lactic acid levels, ROM and exercise-induced pain

Group	Variable	p (sig)			
		Lactic Acid	ROM Dextra	ROM Sinistra	Exercise Pain
SM	Pretest - Posttest 1	0.008 [†]	0.033 [†]	0.007 [†]	
	Pretest - Posttest 2	0.260	0.015 [†]	0.023 [†]	
	Posttest 1 - Posttest 2	0.000 [†]	0.007 [†]	0.003 [†]	0.027 [†]
MS	Pretest - Posttest 1	0.000 [†]	0.023 [†]	0.760	
	Pretest - Posttest 2	0.008 [†]	0.131	0.104 [†]	
	Posttest 1 - Posttest 2	0.008 [†]	0.000 [†]	0.054	0.007 [†]
CMS	Pretest - Posttest 1	0.000 [†]	0.136	0.011 [†]	
	Pretest - Posttest 2	0.376 [*]	0.161	0.840	
	Posttest 1 - Posttest 2	0.000 [†]	0.007 [†]	0.007 [†]	0.003 [†]
CON	Pretest - Posttest 1	0.000 [†]	0.040 [†]	0.007 [†]	
	Pretest - Posttest 2	0.001 [†]	0.010 [†]	0.000 [†]	
	Posttest 1 - Posttest 2	0.000 [†]	0.834 [*]	1.000	0.471 [*]

(*) using the Paired t test; (without*) using the Wilcoxon test; (†)significantly different

combining massage and stretching in accelerating the recovery of lactic acid levels.

Meanwhile, the changes in dextra and sinistra ROM were measured to evaluate muscle flexibility after intervention. In this sense, the SM group showed significant improvement after intervention with $p = 0.015$ from pretest to posttest 2. The left ROM showed a similar improvement, with a p -value of 0.023 in the same generation. In addition, the CMS group was reported to gain optimal results with $p < 0.007$ in various pre- and posttest comparisons. The next variable measured in this study was pain caused by exercise (exercised-induced pain). This variable indicated a notable reduction in both the MS and CMS groups, with a significant decline in pain from posttest 1 to posttest 2. The yielding p -values for both groups were 0.007 and 0.003, respectively. These findings indicate that muscle stretching techniques and a combination of massage and stretching effectively alleviate pain following high-intensity exercise.

Although the findings indicate a positive trend across the groups, the combination of massage and stretching (CMS group) yielded superior outcomes in diminishing lactic acid levels, enhancing range of motion, and alleviating exercise-related discomfort during massage. The substantial decrease in lactic acid levels within the CMS group suggests that the combination of these strategies may represent the most efficacious method for physical recovery among football players.

Other advanced analyses were conducted in this research, involving the MANOVA and Kruskal-Wallis tests. As shown in Table 4, no significant difference is found between any of the groups for the lactic acid level variable (Δ Pretest lactic acid - Posttest 1 lactic acid) and the ROM Dextra variable (Δ Pretest ROM Dextra - Posttest 1 ROM Dextra). This is because the significance value for both variables was more than 0.05 ($p > 0.05$). Apart from these two variables, the results of the MANOVA and Kruskal-Wallis tests for the other two show a significant difference ($p < 0.05$).

Table 5 illustrates the differences in lactic acid, ROM, and exercise pain levels across the groups using the Mann-

Table 4. Manova and Kruskal Wallis test results

	Variable	p (sig)
Lactic acid	Δ Pretest - Posttest 1	0.119
	Δ Pretest - Posttest 2	0.001 [†]
	Δ Posttest 1 - Posttest 2	0.000 [†]
Exercise pain	Δ Posttest 1 - Posttest 2	0.005 [†]
ROM Dextra	Δ Pretest - Posttest 1	0.601 [*]
	Δ Pretest - Posttest 2	0.001 [†]
	Δ Posttest 1 - Posttest 2	0.003 [†]
ROM Sinistra	Δ Pretest - Posttest 1	0.009 [†]
	Δ Pretest - Posttest 2	0.000 [†]
	Δ Posttest 1 - Posttest 2	0.000 [†]

(*) using the Kruskal-Wallis test; (without*) using the MANOVA test; (†)significantly different

Whitney and Bonferroni tests. The results of the Bonferroni test showed that the lactic acid levels of the control group (CON) experienced the slightest decrease in lactic acid levels compared to the SM, MS, and CMS treatment groups ($p < 0.005$). Further, the lactic acid levels of the CMS group decreased better than the SM, MS, and CON groups, with significance values $p = 0.003$, $p = 0.005$, and $p = 0.000$, respectively. Meanwhile, the SM group did not experience a greater decrease in lactic acid levels than the MS group ($p = 1.000$).

For the exercise pain variable, the MS group had a significant effect compared to the CON group. However, when compared to the SM and CSM groups, the results were not significant. This means stretching can reduce pain better than the CON group but not better than the SM and CSM groups. Finally, in the ROM variable, both dextra and sinistra ROM showed that the provision of sports massage, stretching, and a combination of sports massage with stretching had a significant effect on improving ROM after maximum

Table 5. Differences in lactic acid, ROM, and exercise pain in the SM, MS, CMS and CON group

Dependent Variable	Group	p (sig.)			
		Pre-post1	Pre-post2	Post1-post2	
Lactic acid	SM	CMS	-	1.000	0.003 [†]
		MS	-	0.511	1.000
		CON	-	0.114	0.003 [†]
	CMS	MS	-	0.010 [†]	0.005 [†]
		CON	-	0.002 [†]	0.000 [†]
	MS	CON	-	1.000	0.002 [†]
Exercise Pain	SM	CMS	-	-	1.000
		MS	-	-	0.259
		CON	-	-	0.378
	CMS	MS	-	-	0.259
		CON	-	-	0.378
	MS	CON	-	-	0.001 [†]
ROM Dextra	SM	CMS	-	0.272 [*]	0.243 [*]
		SM	-	0.215 [*]	0.701 [*]
		CON	-	0.001 ^{+†}	0.004 ^{+†}
	CMS	SM	-	0.927 [*]	1.000 [*]
		CON	-	0.008 ^{+†}	0.002 ^{+†}
	SM	CON	-	0.005 ^{+†}	0.001 ^{+†}
ROM Sinistra	SM	CMS	0.323	1.000	0.865
		SM	1.000	1.000	1.000
		CON	0.323	0.000 [†]	0.047 [†]
	CMS	MS	0.032 [†]	1.000	0.035 [†]
		CON	1.000	0.002 [†]	0.000 [†]
	MS	CON	0.032 [†]	0.001 [†]	1.000

(*) using the Mann Whitney Test; (without*) using the Bonferroni test; (†) significantly different

intensity running activity ($p < 0.005$). However, the SM group did not outperform the MS group, and vice versa.

Discussion

The study investigates the impact of sports massage, muscle stretching, and a combination of both on the physical recovery of football players during match breaks. In particular, it focuses on lactic acid levels, pain after exercise, and range of motion (ROM). Since blood circulation plays a crucial role in muscle rehabilitation, effective oxygen and nutrient delivery through haemoglobin in red blood cells is essential for muscle health and function (Yoon et al., 2024). Many scholars argue that sports massage and stretching influence recovery by regulating blood flow and velocity, a key factor in muscle healing (González-Alonso, 2012; Joyner & Casey, 2015). The regulation of blood flow to skeletal muscle is crucial to satisfy the oxygen requirements of contracting skeletal muscle and to extend exercise duration.

At the systemic level, one of the main factors that affects this whole response is the production of cardiac output, which is caused by a rise in heart rate and stroke volume. This output

meets the oxygen needs of active muscles and the perfusion pressure of other organs. In humans, these requirements may be adjusted by muscular stretching flexibility exercises, as well as variations in external temperature and pressure (Rowell, 2004).

Having more lactic acid in the body after intense exercise is normal because metabolic products build up during anaerobic activity (Rusdiawan et al., 2020). When lactate levels increase, blood pH decreases. This increase affects enzyme reactions and ATP production, leading to fatigue. Since intracellular acidosis influences muscle fatigue, reducing lactic acid levels to normal is necessary to reduce fatigue (de Lima et al., 2018; Theofilidis et al., 2018). In maximal exercise for 30-120 seconds, lactate levels can reach 15-25 mM, measured after 3-8 minutes of exercise. Generally, high levels of lactic acid indicate ischemia and hypoxia (Rusdiawan & Habibi, 2020a; Goodwin et al., 2007).

In this study, the combination of sports massage and stretching (CMS group) was documented as the most significant intervention that reduced lactic acid levels. It was more significant than sports massage only (SM group) or stretching only (MS group). This is in line with previous findings showing that massage helps accelerate blood and lymphatic circulation while stretching helps restore muscle length and prevent stiffness. Both contribute to the acceleration of lactic acid removal from muscles (Ferreira et al., 2011; Greenwood et al., 2008; Menzies et al., 2010).

Although exercise in the long term will increase muscle flexibility and reduce the risk of injury (Warneke et al., 2023), acutely, high-intensity exercise can reduce Range of Motion (ROM) (Jamurtas et al., 2005; Nosaka et al., 2002). Such decrease is caused by increased delayed onset muscle soreness and decreased range of motion (ROM) associated with connective tissue damage (Leite et al., 2023). Further, high-intensity exercise may trigger muscle pain, as expressed by Stožer, Vodopivec and Bombek (2020). If a person is unaccustomed to a specific exercise or if the intensity is greater than normal intensity or duration. High-intensity eccentric exercise most often causes exercise-induced muscle damage (EIMD). This is likely due to the recruitment of fewer motor units during eccentric exercise compared to other modes of contraction, leading to a higher force per active motor unit and increased mechanical stress (Stožer et al., 2020).

An effective recovery strategy is essential to maintain optimal performance and prevent overtraining or injury, enabling athletes to continue the next match in a stable condition with good performance (Dakić et al., 2023). In this study, the CMS group showed the most optimal results in all measured variables, indicating that the combination method is more effective than either method alone. Massage and stretching have complementary mechanisms in muscle recovery: massage facilitates recovery by increasing blood circulation, while stretching helps reduce muscle tension and increase flexibility. This combination appears to have a greater cumulative effect on post-workout recovery than either method alone (Weerapong, Hume, & Kolt, 2005a; Yoon et al., 2024).

Previous research suggests that muscular stretching can reduce muscle injury and exhaustion at the onset and conclusion of training and competition. However, the effectiveness of this technique varies depending on the

timing, methodology, and duration of the stretching. Both static and active stretchings significantly reduce lactate levels (Pinar et al., 2012). Sports massage is a technique for muscle rehabilitation that includes pressure application, diminishes passive muscular stiffness, elevates arterial pressure, and facilitates rapid muscle recovery (Weerapong, Hume, & Kolt, 2005b). Moreover, changes in heart rate and blood pressure following massage stimulate parasympathetic nerve activity, restoring the aroused body to a state of equilibrium (Jo et al., 2018).

In neurological models, massage is thought to improve pain relief and speed up muscle recovery by changing pain control mechanisms like mechanoreceptor and nociceptor sensitisation and diffuse pain inhibitory regulation (Aboodarda et al., 2015; Kent-Braun et al., 2012). It is believed to facilitate cellular gas exchange by exerting external pressure on the muscles to enhance blood circulation. Hence, massage is considered helpful in getting rid of any leftover oxidation in the muscles after exercise by improving blood flow to the limbs and small blood vessels (Barber et al., 2020; Kalichman & Ben David, 2017; Pointon & Duffield, 2012). The primary benefits of massage include alleviation of muscular discomfort, enhancement of parasympathetic nerve blood flow and circulation, and mitigation of inflammatory responses and associated trigger points, and physiological research indicates its efficacy in muscle recovery (Okamoto et al., 2013).

The combination of sports massage and stretching may provide a synergistic impact on the recovery process. Sports massage alleviates muscular tension and enhances circulation while stretching increases flexibility and range of motion. The increased blood flow from massage and the increased range of motion from stretching may help get rid of lactic acid faster, speed up the recovery of muscle function, and ease pain after long-term physical activity.

Current studies indicate that sports massage can beneficially influence an athlete's psychological preparedness, improve athletic performance, and facilitate recovery from training and competition (Brummitt, 2008). A thorough analysis indicated that massage may enhance skeletal muscle recovery following intense exercise, perhaps by augmented blood flow, less muscular spasm, and reduced inflammation (Best et al., 2008). Moreover, stretching has had a positive impact on muscle recovery, with research demonstrating that physical relaxation strategies, such as stretching, might mitigate occupational stress among healthcare professionals (Zhang et al., 2021).

Conclusions

In conclusion, the study found that a combination of sports massage and muscle stretching during a match break can accelerate the physical recovery of football players. This approach is better for reducing lactic acid levels, increasing range of motion, and reducing post-exercise pain rather than using massage or stretching alone. The treatment also helps reduce muscle fatigue and increases flexibility. The findings suggest that coaches and medical teams should consider this strategy to maximise player recovery, maintain optimal performance, and reduce injury risk due to muscle fatigue and strain. This strategy is particularly beneficial in sports requiring high energy and intense activity, like football.

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Conflict of interest

All researchers declare that there is no conflict of interest in this research.

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Синергетичний вплив комбінованого методу масажу та стретчингу під час перерви між таймами на прискорене відновлення у футболі: Квазіекспериментальне дослідження щодо кліренсу молочної кислоти, зменшення болю та поліпшення показників гнучкості

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 14 с., 5 табл., 1 рис., 67 джерел.

Історія питання. Футболісти часто стикаються зі зниженням результативності на початку другого тайму через зменшення температури м'язів і накопичення індикаторів втоми, як-от молочна кислота.

Мета дослідження. Мета цього дослідження полягала у вивченні ефективності масажу, стретчингу та їх комбінації у сприянні фізичному відновленню під час перерви між таймами в матчі. Дослідження було зосереджено на швидкості виведення молочної кислоти з організму, ступені зменшення дискомфорту від фізичних навантажень та поліпшенні показників гнучкості.

Матеріали та методи. У цьому дослідженні застосовано квазіекспериментальний дизайн, до якого було залучено 36 футболістів-чоловіків з футбольного клубу UNESA FC. Цих гравців було розділено на чотири групи: спортивний масаж (СМ), розтягування м'язів (РМ), комбінація спортивного масажу і розтягування м'язів (КМР) та контрольна (КОН). Учасники виконували біг на біговій доріжці з максимальною інтенсивністю (90–95 % від максимальної частоти серцевих скорочень), після чого проходили визначені процедури відновлення: СМ, РМ, КМР та КОН. На етапах перед початком, під час та після завершення інтервенції проведено контроль рівнів молочної кислоти (вимірювали за допомогою лактометра), діапазону рухів (вимірювали за допомогою гоніометра) та рівнів інтенсивності болю (вимірювали за допомогою візуальної аналогової шкали). Згодом отримані показники піддавали статистичному аналізу, що включав t-критерії для парних вибірок, критерії Вілкоксона, багатовимірний дисперсійний аналіз (MANOVA) та критерії Краскела-Волліса.

Результати. Це дослідження показало, що у групі, де застосовувалася практика комбінованого методу, спостерігалось найзначніше зниження рівня молочної кислоти (з $12,68 \pm 2,37$ до $5,16 \pm 1,04$ ммоль/л, $p = 0,000$), що перевищувало показники груп СМ, РМ та КОН ($p < 0,005$). Крім того, показники зменшення болю також виявилися значущими в групах КМР ($3,44 \pm 2,35$ до $1,67 \pm 1,58$) та РМ ($4,67 \pm 1,11$ до $1,33 \pm 1,00$) ($p < 0,05$). Аналогічним чином, покращення гнучкості

було вищим у групі КМР (правий діапазон рухів: $p = 0,007$; лівий діапазон рухів: $p = 0,003$), тоді як у контрольній групі не спостерігалося виражених змін. Тест MANOVA виявив істотні міжгрупові відмінності в результатах постінтервенційного періоду ($p < 0,05$).

Висновки. Результати представленого дослідження свідчать, що поєднання стретчингу та масажу під час перерви між таймами футбольного матчу сприяє максимізації відновлення організму за рахунок зниження рівня молочної кислоти, полегшення дискомфорту та поліпшення показників гнучкості або амплітуди рухів. Такий підхід знижує рівень спаду результативності у другому таймі та ризику травмування.

Ключові слова: футбол, масаж, стретчинг, відновлення.

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Determining the Potential of L-Selenomethionine as a Protective Agent Against Exercise-Induced Muscle Damage

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Abstract

Background. Delayed-Onset Muscle Soreness (DOMS) is a phenomenon that arises from muscle damage following uncommon or intense eccentric exercise, with symptoms persisting for a few days. The condition is characterized by muscle pain, reduced muscle strength, limited range of motion, and general discomfort that affects performance and disrupts the exercise program.

Objectives. This study aimed to investigate the effect of Selenium supplementation on DOMS and muscle damage after performing heavy eccentric exercise.

Materials and methods. An experimental pre-post control group design was used in this study. A total of 44 male students from the Sports Science Department of the State University of Surabaya (Universitas Negeri Surabaya) were randomly and double-blindly assigned to either a selenium supplementation group ($n = 22$) or a placebo group ($n = 22$). The participants in both groups were instructed to consume one selenium or placebo capsule for 28 days. Following the 28-day supplementation period, both groups underwent a 10-set x 10-rep bench stepping-test. Delayed Onset Muscle Soreness (DOMS) and Creatine Kinase (CK) levels were assessed at 24 and 48 hours in the post-exercise phase.

Results. The findings of the study demonstrated that during the 24 to 48-hour period following heavy eccentric exercise, both groups experienced a reduction in Delayed Onset Muscle Soreness (DOMS) and CK plasma levels. However, the selenium supplementation group exhibited a significantly greater reduction in DOMS and CK levels compared to the placebo group ($p < 0.05$). This suggests that selenium supplementation may enhance the natural recovery process, rather than being solely responsible for the observed reduction in these markers.

Conclusions. In conclusion, Selenium supplementation may lower the likelihood of muscle injury following heavy eccentric exercise, as it effectively decreases plasma DOMS and CK levels in the bloodstream.

Keywords: eccentric exercise, muscle damage, inflammation, sports injured.

Introduction

Exercise-induced muscle damage (EIMD) is a physiological response that commonly occurs following unaccustomed or strenuous physical activity, particularly those involving high mechanical stress such as eccentric muscle contractions. One of the most recognizable

clinical manifestations of EIMD is Delayed Onset Muscle Soreness (DOMS), a prevalent condition among athletes and physically active individuals (Ali et al., 2023). Unlike acute or immediate pain, DOMS is characterized by delayed muscular discomfort that typically begins 12–24 hours post-exercise, peaks between 24–72 hours, and gradually subsides within 5–7 days (Hotfiel et al., 2018; Kristensen et al., 2021; Zulaini et al., 2021). This condition frequently results from activities such as running, plyometrics, strength training, and other high-intensity exercises that involve eccentric contractions (Chang et al., 2021), which include muscle actions during lengthening, braking, or decelerating

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movements. The underlying mechanism of EIMD involves structural disruption of muscle fibers, inflammation, oxidative stress, and subsequent repair processes. Symptoms include localized pain, stiffness, muscle tenderness, reduced range of motion, swelling, and temporary muscle weakness (Wilke & Behringer, 2021; Yoshida et al., 2022). The extent of muscle damage is influenced by factors such as exercise intensity, volume, and the predominance of eccentric loading. Understanding the mechanisms and outcomes of EIMD is essential for developing effective recovery strategies and protective interventions.

DOMS is often triggered by inflammation in the affected area due to muscle fiber damage, and it is usually assessed by tracking changes in creatine kinase and lactate dehydrogenase (LDH) levels in the bloodstream (Beba et al., 2022; Boukhris et al., 2020). Numerous reports indicate that exercise-induced muscle damage (EIMD) commonly occurs after strenuous, unaccustomed exercises, especially those involving high frequencies of eccentric contractions. Although not classified as a disease or disorder, DOMS can hinder athletes' participation in subsequent training sessions (Udani et al., 2009). The soreness and stiffness can restrict the range of motion, making it challenging for athletes to maintain proper technique and form during exercises (Rickards et al., 2021).

The specific mechanisms responsible for the damage caused by exercise have not been extensively explained (O'Malley et al., 2024). Nevertheless, prior research has shown that delayed-onset muscle damage is primarily triggered by mechanical stress, particularly eccentric muscle contractions (Markus et al., 2021). Heavy eccentric exercise has played a significant role in damaging cell membranes, leading to greater microtrauma within the muscle fibers (Tomalka, 2023). This microscopic muscle injury is initiated by mechanical disruptions to sarcomeres, which in turn cause an inflammatory response involving T-tubules, myofibrils, cytoskeletal proteins, and the sarcoplasmic reticulum (Toigo, 2023).

Several studies have focused on efforts to minimize the risk of DOMS and muscle damage (Angelopoulos et al., 2022; Anthony et al., 2021; Fedewa et al., 2019). These efforts involve the use of antioxidant supplements and other potential agents (Barker et al., 2023; McHugh et al., 1999). However, the outcomes from these studies differ, which underlines the need for additional research as an attempt to reduce the risk of DOMS and muscle damage. Taking these circumstances into account, it is crucial to explore alternative nutritional interventions that can be used to prevent DOMS and muscle damage resulting from heavy eccentric exercise. One such alternative that can be considered is L-Selenomethionine (L-Semet).

L-Semet was chosen as the intervention in this study due to its essential role as a trace element with significant antioxidant and anti-inflammatory properties (Williamson & Davison, 2020). As a key organic form of selenium, L-Semet is better absorbed and retained in the body compared to inorganic selenium compounds. It functions as a precursor for selenoproteins, playing a crucial role in mitigating oxidative stress and modulating inflammatory responses through its involvement in the glutathione peroxidase (GPx) and thioredoxin reductase (TrxR) enzyme systems (Mazloomi et al., 2021; Ringuet et al., 2021). These mechanisms are particularly relevant in the context of DOMS and EIMD, both of which are largely triggered

by increased oxidative stress and inflammation following intense eccentric muscle contractions.

Previous studies have demonstrated that higher selenium levels can accelerate muscle recovery by reducing reactive oxygen species (ROS) production and inhibiting pro-inflammatory pathways, such as the NF- κ B signaling cascade (Fernández-Lázaro et al., 2020; Prabhu et al., 2002). Additionally, L-Semet has been shown to contribute to maintaining cell membrane integrity, thereby minimizing exercise-induced muscle damage. Compared to other antioxidants, such as vitamins C and E, L-Semet offers a distinct advantage by interacting with the body's endogenous antioxidant defense system without impeding physiological adaptations to exercise.

The use of L-Selenomethionine (L-Semet) is anticipated to be a promising strategy for mitigating the adverse effects of intense eccentric exercise. As a natural trace element, L-Semet possesses potent anti-inflammatory properties and helps attenuate oxidative stress by suppressing the production of pro-inflammatory cytokines and reactive oxygen species. Moreover, L-Semet plays a vital role in various biological functions, including immune regulation and thyroid hormone metabolism. One of the key markers of exercise-induced muscle damage (EIMD) is the elevation of creatine kinase levels in the bloodstream (Lamb et al., 2019; Sánchez Díaz et al., 2022), which reflects sarcolemmal disruption and leakage of intracellular enzymes into the circulation (Stožer et al., 2020). Monitoring CK levels provides an objective biochemical measure of muscle damage severity.

Considering these factors, this study aims to investigate the potential of L-Selenomethionine (L-Semet) as a protective agent against exercise-induced muscle damage (EIMD), by evaluating its effectiveness in reducing delayed onset muscle soreness (DOMS) and the subsequent rise in creatine kinase (CK) levels following high-intensity eccentric exercise. The findings are expected to provide valuable insights into the role of L-Semet in enhancing muscle recovery and athletic performance.

Materials and Methods

Study Participants

This study utilized a randomized, double-blind, placebo-controlled experimental design with a pretest-posttest control group approach. A total of 44 recreationally active male students from the Sports Science Department of Universitas Negeri Surabaya participated in the study. The study aimed to evaluate the potential role of selenium supplementation in mitigating muscle soreness and damage, specifically focusing on its effects on individuals engaged in physical activity.

A power analysis using G*Power software (version 3.1.9.7) was conducted to determine the required sample size. Based on previous studies investigating the effects of antioxidant supplementation on muscle soreness and damage, we assumed an effect size of 0.8, a power of 0.80, and an alpha level of 0.05. The analysis determined a minimum of 20 participants per group to detect statistically significant differences. To account for potential dropout, the final sample size was increased to 22 participants per group ($n = 44$).

Participants who meet the inclusion criteria for this study are recreationally active males who engage in physical activity at least three times per week. They must be in good health,

have a normal Body Mass Index (BMI), be non-smokers, and not take any medications or dietary supplements during the study. Additionally, they must be willing to abstain from high-intensity physical activity throughout the study period.

Conversely, individuals with a history of musculoskeletal disorders or chronic injuries will be excluded. Those who are currently or have recently participated in a structured resistance training program, have used antioxidant supplements or anti-inflammatory medications within one month prior to the study, or have metabolic, cardiovascular, or neuromuscular diseases will also be ineligible. Furthermore, individuals with allergies or intolerances to selenium supplementation will not qualify for participation.

Participants were randomly assigned to either the L-Semet Group (n=22) or the Placebo Group (n = 22) using a computer-generated randomization list. Both participants and researchers involved in data collection and analysis were blinded to group assignments until the study was completed to minimize bias. The study was conducted in a double-blind manner, ensuring that neither participants nor researchers knew the group assignments until after data analysis.

Study Organization

This study was a randomized double-blind placebo-controlled experiment with a pretest-posttest control group design, aiming to assess the effectiveness of 200µg L-Selenomethionine (L-Semet) capsule supplementation for 4 weeks against DOMS and CK as markers of muscle damage following eccentric exercise. The research lasted a month, starting with an initial evaluation on the first day to determine participants' condition. Throughout the study, they were restricted from any exercise except on the experimental day.

During the screening day visit, participants filled out a physical fitness capacity form, providing details on their weekly running frequency and volume, injury and illness history, and medications used within two weeks before the study. At the first visit, both the L-Semet Group (LG) and the Placebo Group (PL) underwent baseline measurements including body weight, height, body fat percentage, physical activity, and VO₂Max. Body fat percentage was assessed using a Tanita BC-730 Bioelectrical Impedance Analyzer. VO₂Max was estimated through the multistage 20-meter shuttle run test and calculated using the Leger equation. Physical activity level was evaluated using the International Physical Activity Questionnaire (IPAQ) short form, and reported as metabolic equivalent task (MET)-minutes per week (MET-min/week).

Supplementation

The L-Semet Group (n = 22) received capsules containing 200 µg of L-Selenomethionine (L-Semet), while the Placebo Group (n = 22) received identical capsules containing 100 mg of corn starch. Both groups consumed one capsule daily with breakfast for 28 days. To minimize potential confounding variables, participants were instructed to avoid strenuous physical activity throughout the study period.

The 200 µg/day dose of L-Semet was selected based on prior research indicating its effectiveness in enhancing antioxidant enzyme activity, particularly glutathione peroxidase (GPx), without inducing toxicity (Kyrgios et al., 2019). Studies investigating selenium's impact on oxidative stress and inflammation in relation to exercise and muscle recovery have shown that doses between 200–400 µg/day can effectively reduce lipid peroxidation and enhance antioxidant capacity. Considering that the tolerable upper intake level (UL) for selenium is 400 µg/day, a 200 µg/day dose was chosen to ensure efficacy in mitigating delayed onset muscle soreness (DOMS) and reducing creatine kinase (CK) plasma levels while maintaining a safe intake threshold.

L-Selenomethionine (L-Semet) was selected due to its superior bioavailability compared to inorganic selenium forms such as selenite or selenate (Mal'tseva et al., 2022). This specific dose has been previously utilized in research examining selenium's effects on inflammation modulation and muscle recovery, supporting its application in the present study.

The L-Selenomethionine supplement used in this study was Solgar® L-Selenomethionine 100 mcg, manufactured by Solgar Inc., USA, a reputable company known for producing high-quality nutritional supplements in compliance with Good Manufacturing Practices (GMP). This product is commercially available over the counter and widely distributed in both physical and online markets. Each tablet contains 100 mcg of selenium in the bioavailable form of L-selenomethionine. Documentation confirming product quality and safety, including the Certificate of Analysis (COA) and labeling information, was obtained from the manufacturer and is available upon request. The supplement is free from gluten, dairy, soy, and artificial additives, and is suitable for vegetarians.

Exercise Protocol

After 28 days of supplementation, participants underwent damaging exercise during the second visit to assess the Exercise-Induced Muscle Damage (EIMD) effect. They performed a single bout of eccentric exercise using the Newham

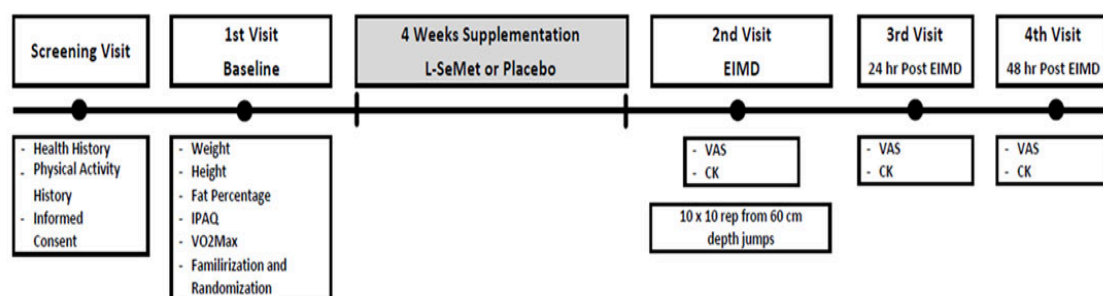


Fig. 1. Study Design

bench-stepping modification exercise protocol (Newham et al., 1983), which consists of 10 sets x 10 repetitions of bench-stepping tests with 1-minute intervals. This protocol has been proven to cause pain sensation (DOMS) in the quadriceps muscles of the leg that underwent eccentric exercise.

To assess DOMS and CK levels as muscle damage markers, participants were evaluated 24 hours (3rd visit) and 48 hours (4th visit) post-eccentric exercise. Throughout the 30-day study period, participants remained uninjured, avoided all physical activity, and were instructed not to consume anti-inflammatory drugs, treatments, or additional dietary supplements. A summary of the study design is presented in Figure 1.

This study followed ethical standards and received approval from the Health Research Ethics Committee, Faculty of Public Health, Airlangga University, and has been deemed ethically acceptable with the identity number: 104/EA/KEPK/2023.

Outcome Measure

This study used a Visual Analogue Scale (VAS) with a 100mm range to assess the level of pain sensation from DOMS. The VAS score ranged from 0mm (no pain) to 100mm (maximum tolerable pain) (Fleckenstein et al., 2021). This assessment was conducted 24 hours and 48 hours after the bench stepping test protocol to evaluate pain in the quadriceps muscle of the leg that underwent eccentric exercise. Using VAS is a common method in the literature for assessing acute exercise-induced pain.

Blood samples were collected from the cubital vein and treated with EDTA to assess plasma levels of CK. The samples were centrifuged at 3000 rpm for 15 minutes, and the resulting plasma was stored at -20°C in a freezer until analysis. CK levels were assessed 24 hours (3rd visit) and 48 hours (4th visit) post EIMD. The plasma samples were analyzed using the Glory Diagnostics (Barcelona, Spain) CK commercial ELISA kit. The assessment of CK plasma was conducted at the Institute of Tropical Disease and International Research Center Laboratory, Universitas Airlangga Indonesia, to obtain the CK plasma data.

Statistical Analysis

The normality of data distribution was assessed using the Shapiro-Wilk test. To compare VAS scores and CK plasma levels across three time points (1 hour before, 24 hours post, and 48 hours post) within each group, a repeated-measures ANOVA was performed. Additionally, a two-way ANOVA was conducted to assess the main effects of group (L-Semet vs. placebo), time (1 hour before, 24 hours post, and 48 hours post), and their interaction on VAS scores and CK plasma levels. If a significant time or interaction effect was detected, post hoc tests were conducted to identify specific differences. Independent t-tests were used to compare VAS scores and CK plasma levels between groups at each time point. All statistical analyses were performed using SPSS version 23, and data were reported as mean $\pm$ SD.

Results

Respondent Characteristic

A total of 44 students, with a mean age of 19.21 years (± 0.79) and a mean BMI of 22.53 (± 0.67), participated

in this study. These male recreational students from the Sports Sciences Department at Universitas Negeri Surabaya voluntarily participated after providing informed consent. Participants were randomly divided into two groups: the L-Semet supplementation group and the placebo group. The mean age of the L-Semet group was 19.19 years (± 0.65), while the placebo group had a mean age of 19.31 years (± 0.87). Table 1 presents the baseline characteristics of both groups, including age, height, weight, BMI, fat percentage, IPAQ, and VO_{2max} .

The data in Table 1 confirm that both groups were comparable in terms of baseline characteristics, suggesting that any differences observed in later analyses are likely due to the effects of L-Semet supplementation rather than pre-existing variations.

Table 1. Respondent Characteristic

Variable	L-Semet Group Mean $\pm$ SD	Placebo Group Mean $\pm$ SD	P
Age (years)	19.19 $\pm$ 0.65	19.31 $\pm$ 0.87	0.130
Height (cm)	166.29 $\pm$ 4.50	167.86 $\pm$ 5.02	0.144
Weight (kg)	62.36 $\pm$ 3.52	63.43 $\pm$ 3.46	0.663
BMI (kg/m ²)	22.54 $\pm$ 0.67	22.51 $\pm$ 0.70	0.916
Fat Percentage (%)	21.35 $\pm$ 3.50	20.97 $\pm$ 3.13	0.534
IPAQ (MET-min/week)	1164.93 $\pm$ 230.26	1291.36 $\pm$ 137.0	0.432
VO_{2max} (mL/kg-min)	35.76 $\pm$ 4.31	37.50 $\pm$ 3.61	0.567

These baseline characteristics indicate that both groups were well-matched, ensuring fair comparisons in subsequent analyses.

Table 2 presents the Kolmogorov-Smirnov normality test results for DOMS and CK plasma levels. All p-values exceed 0.05, confirming that the data follow a normal distribution.

Table 2. Normality test result

Variable	Time Point	L-Semet Sig.	Conclusion	Placebo Sig.	Conclusion
DOMS	1-h before (Baseline)	0.137	Normal	0.117	Normal
	24-h post	0.085	Normal	0.159	Normal
	48-h post	0.200	Normal	0.135	Normal
CK	1-h before (Baseline)	0.200	Normal	0.200	Normal
	24-h post	0.200	Normal	0.200	Normal
	48-h post	0.200	Normal	0.200	Normal

The normality test results in Table 2 show that all measured variables had p-values greater than 0.05, indicating a normal distribution. This allows for the use of parametric tests in subsequent analyses.

Since all p-values exceeded 0.05, the data were considered normally distributed. Additionally, a Levene test was performed to assess homogeneity of variances, as shown in Table 3.

The results of the homogeneity test in Table 3 confirm that the variances were homogeneous across groups, meaning that statistical comparisons between the two groups can be conducted with confidence.

Table 3. Homogeneity test result. Levene test

Variable	1-h L-Semet – Placebo Sig.	24-h L-Semet – Placebo Sig.	48-h L-Semet – Placebo Sig.
DOMS	0.264	0.362	0.653
CK	0.448	0.838	0.999

The normality test (Kolmogorov-Smirnov) indicated that the data was normally distributed ($p > 0.05$), and the homogeneity test confirmed equal variances. To analyze differences in DOMS scores and CK plasma levels over time within each group, a repeated measures ANOVA with Bonferroni post-hoc correction was conducted. The Bonferroni correction was used to account for multiple comparisons and control the familywise error rate. This statistical approach was employed to determine if there was a significant decrease in DOMS and CK plasma levels over the 28-day L-Semet supplementation period compared to the placebo group.

Pain Assessment Result

Delayed onset muscle soreness (DOMS) typically occurs following intense or unfamiliar eccentric contractions and may persist for several days post-exercise. It is commonly associated with muscle damage. The intensity of DOMS was assessed in the quadriceps using the Visual Analog Scale (VAS) at 1 hour before, and at 24- and 48-hours post-exercise, as presented in Table 4.

Table 4. Pain Score Post Heavy Eccentric Exercise (VAS) (Values expressed in millimeters [mm] based on a 0–100 mm visual analog scale; values are presented as mean $\pm$ standard deviation [SD])

Group	1-h before Mean $\pm$ SD	24-h post Mean $\pm$ SD	48-h post Mean $\pm$ SD	p
L-Semet	4.50 $\pm$ 0.84	35.50 $\pm$ 1.25	21.00 $\pm$ 1.10	0.000
Placebo	4.30 $\pm$ 0.82	44.50 $\pm$ 1.14	34.66 $\pm$ 0.95	0.000

At baseline (1 hour prior to exercise), there was no statistically significant difference in DOMS scores between the L-Semet (4.50 $\pm$ 0.84 mm) and placebo groups (4.30 $\pm$ 0.82 mm; $p > 0.05$). At 24 hours post-exercise, the placebo group experienced significantly greater muscle soreness (44.50 $\pm$ 1.14 mm) compared to the L-Semet group (35.50 $\pm$ 1.25 mm; $p < 0.001$). This trend continued at 48 hours, where DOMS scores remained significantly lower in the L-Semet group (21.00 $\pm$ 1.10 mm) compared to the placebo group (34.66 $\pm$ 0.95 mm; $p < 0.001$).

To evaluate the effectiveness of L-Semet supplementation in reducing DOMS after heavy eccentric exercise, a two-way ANOVA was performed. This analysis assessed the main effects of two independent variables—group (L-Semet vs. Placebo) and time (1 hour before, 24 hours post, and 48 hours post-exercise)—on the dependent variable (DOMS scores), as well as their interaction effect.

The main effects determine whether there are significant differences in DOMS scores between groups and across time points. The interaction effect assesses whether the pattern of change in DOMS over time differs between the two groups. The results of the two-way ANOVA are presented in Table 5.

Table 5. Results of Two-Way ANOVA on DOMS Scores

Source of Variation	F	p	Significance
Group	1667.43	1.61×10^{-74}	Highly significant
Time	12998.95	1.12×10^{-146}	Highly significant
Group $\times$ Time	493.82	2.39×10^{-60}	Highly significant

The results of the two-way ANOVA indicate that there was a significant main effect of group on DOMS scores ($F = 1667.43$, $p = 1.61 \times 10^{-74}$), demonstrating a substantial difference in pain levels between the L-Semet and placebo groups. Additionally, there was a significant main effect of time ($F = 12998.95$, $p = 1.12 \times 10^{-146}$), indicating that DOMS scores changed significantly at different time points (1 hour before, 24 hours post, and 48 hours post-exercise).

Moreover, the analysis revealed a significant interaction effect between group and time ($F = 493.82$, $p = 2.39 \times 10^{-60}$). This interaction suggests that the pattern of change in DOMS scores over time differed significantly between the L-Semet and placebo groups, implying that the effectiveness of L-Semet in reducing DOMS varied at different post-exercise time points.

These findings demonstrate that L-Semet supplementation significantly reduces DOMS compared to the placebo, particularly at the post-exercise time points, indicating that the supplement's effectiveness is influenced by the duration of recovery.

Muscle Damage Assessment Result

Creatine Kinase (CK) is an enzyme released into the bloodstream when muscle fibers are damaged, commonly observed after intense or unfamiliar eccentric exercise. Elevated CK levels are widely used as a biomarker for muscle damage and recovery. In this study, CK plasma levels were measured at baseline (1 hour before exercise), as well as at 24 hours and 48 hours post-exercise, to assess the extent of muscle damage and recovery following L-Semet supplementation. The results are presented in Table 6.

Table 6. CK Plasma Levels Across Time Points (Values expressed in International Units per Liter [IU/L]; values are presented as mean $\pm$ standard deviation [SD])

Group	1-h before Mean $\pm$ SD	24-h post Mean $\pm$ SD	48-h post Mean $\pm$ SD	p
L-Semet (IU/L)	82.16 $\pm$ 4.58	349.16 $\pm$ 27.19	243.56 $\pm$ 17.81	0.000
Placebo (IU/L)	80.22 $\pm$ 0.64	354.81 $\pm$ 56.34	307.68 $\pm$ 41.52	0.000

At baseline (1 hour prior to exercise), CK levels were comparable between the L-Semet (82.16 $\pm$ 4.58 IU/L) and placebo groups (80.22 $\pm$ 0.64 IU/L; $p > 0.05$). At 24 hours post-exercise, CK levels peaked significantly in both groups, with the placebo group showing slightly higher levels (354.81 $\pm$ 56.34 IU/L) compared to the L-Semet group (349.16 $\pm$ 27.19 IU/L; $p < 0.001$). By 48 hours post-exercise, CK levels decreased in both groups; however, the L-Semet group exhibited a significantly greater reduction (243.56 $\pm$ 17.81 IU/L) compared to the placebo group (307.68 $\pm$ 41.52 IU/L; $p < 0.001$).

To assess the effects of L-Semet supplementation on CK levels following heavy eccentric exercise, a two-way ANOVA

was performed. This analysis examined the main effects of two independent variables—group (L-Semet vs. Placebo) and time (1 hour before, 24 hours post, and 48 hours post-exercise)—on the dependent variable (CK levels), as well as their interaction effect. The aim was to determine whether there were significant differences in CK levels between the two groups at the different time points, and whether the effect of time varied across groups. The results of the two-way ANOVA are presented in Table 7.

Table 7. Results of Two-Way ANOVA on CK Level

Source of Variation	F	p	Significance
Group	16.50	8.50×10^{-5}	Significant
Time	815.59	$< 1.00 \times 10^{-5}$	Significant
Group $\times$ Time	493.82	3.27×10^{-6}	Significant

The results of the two-way ANOVA indicate that there was a significant main effect of group on CK levels ($F = 16.50$, $p = 8.50 \times 10^{-5}$), demonstrating a substantial difference in CK concentrations between the L-Semet and placebo groups. Additionally, there was a significant main effect of time ($F = 815.59$, $p < 1.00 \times 10^{-5}$), indicating that CK levels changed significantly across the three time points (1 hour before, 24 hours post, and 48 hours post-exercise).

Furthermore, the analysis revealed a significant interaction effect between group and time ($F = 13.99$, $p = 3.27 \times 10^{-6}$). This interaction suggests that the pattern of change in CK levels over time differed significantly between the L-Semet and placebo groups, implying that the effectiveness of L-Semet supplementation in reducing CK levels varied at different post-exercise time points.

These findings demonstrate that L-Semet supplementation significantly reduces CK levels compared to the placebo, particularly at post-exercise time points, indicating that the supplement's effectiveness in attenuating muscle damage is influenced by the duration of the recovery period.

Discussion

Engaging in high-intensity eccentric exercise is well known to cause exercise-induced muscle damage (EIMD), leading to symptoms such as muscle soreness, stiffness, and reduced range of motion, ultimately affecting muscle force production (Martínez-Ferrán et al., 2022). One of the most common manifestations of EIMD is Delayed Onset Muscle Soreness (DOMS), which affects both elite and novice athletes, particularly after unaccustomed eccentric exercise (Chang et al., 2021; Fleckenstein et al., 2021). DOMS is characterized by muscle pain resulting from micro-injury events and has been associated with increased oxidative stress and inflammation (Sara, 2021). The damage induced by eccentric contractions is hypothesized to result from the simultaneous stretching and contracting of muscle fibers, causing structural disruption in Z-disks and myofibrils (Bontemps et al., 2020; Qian et al., 2023).

EIMD occurs primarily due to mechanical stress and metabolic disturbances (Tanabe et al., 2021). The repeated eccentric contractions lead to excessive strain on muscle fibers, particularly in the sarcomere structure, causing mechanical tearing of actin and myosin filaments (Stožer et al., 2020). Additionally, the disruption of sarcolemma

integrity results in calcium influx into the cytoplasm, activating proteolytic enzymes such as calpains and caspases, which further degrade muscle proteins and exacerbate cellular damage (Cordingley et al., 2022). This process triggers an inflammatory response characterized by the release of pro-inflammatory cytokines such as IL-6, TNF- α , and IL-1 β , which recruit immune cells like neutrophils and macrophages to the damaged tissue (Hotfiel et al., 2018). While this immune response is essential for muscle repair, excessive inflammation and oxidative stress can prolong recovery and impair muscle function (de Sousa et al., 2021).

Athletes frequently experience DOMS, which can hinder performance and muscle recovery (Angelopoulos et al., 2022). L-Selenomethionine (L-Semet) supplementation has the potential to accelerate post-exercise recovery and reduce muscle soreness, enabling individuals who regularly perform eccentric exercises to maintain performance levels. This study aimed to investigate the effects of L-Semet supplementation on muscle soreness and recovery following eccentric exercise.

The results of the pain score assessment of DOMS using the VAS indicated that at baseline (1 hour before exercise), there was no statistically significant difference in pain levels between the L-Semet (4.50 ± 0.84 mm) and placebo groups (4.30 ± 0.82 mm; $p > 0.05$). However, following eccentric exercise, the placebo group experienced a significantly greater increase in muscle soreness compared to the L-Semet group. Over time, the pain levels in the L-Semet group decreased more rapidly, indicating that selenium supplementation effectively reduces muscle soreness and accelerates recovery. This finding suggests that L-Semet may help mitigate the negative effects of eccentric exercise on muscle function, potentially allowing for more consistent training adaptations.

Similarly, the CK plasma analysis demonstrated that both groups exhibited a substantial increase in CK levels following exercise, indicative of muscle damage. However, during the recovery phase, CK levels declined more significantly in the L-Semet group compared to the placebo group. This suggests that L-Semet supplementation plays a role in mitigating muscle damage and promoting faster muscle recovery. However, compared to previous studies, the reduction in CK levels observed in this study was relatively modest, which may indicate a dose-dependent response or the influence of individual baseline L-Semet levels.

Statistical analyses further confirmed the significant differences between time points, supporting the hypothesis that L-Semet supplementation aids in muscle recovery. These findings align with previous research suggesting that L-Semet's antioxidant and anti-inflammatory properties contribute to muscle protection and faster recovery (Fernández-Lázaro et al., 2020; Khazdouz et al., 2023). Selenium is known to enhance endogenous antioxidant defense mechanisms by activating the Nrf2 pathway and modulating the inflammatory response through NF- κ B inhibition (Wang et al., 2022; Zhao et al., 2021). This dual action helps protect muscle tissues from oxidative stress while maintaining essential physiological adaptations to exercise.

Eccentric exercise significantly increases mitochondrial activity and oxygen consumption, leading to elevated ROS production (Irawan et al., 2022; Jakubczyk et al.,

2020). While moderate ROS production is necessary for cell signaling and adaptation, excessive ROS levels can overwhelm endogenous antioxidant defenses, resulting in muscle damage and delayed recovery (Arazi et al., 2021; Thirupathi et al., 2021). The balance between oxidative stress and adaptive responses is crucial, as excessive antioxidant supplementation may blunt beneficial training adaptations (Zachariah et al., 2021). Future studies should explore whether L-Semet supplementation affects long-term muscle adaptation to exercise.

Athletes commonly use antioxidant supplementation to combat oxidative stress and reduce exercise-induced fatigue (Botek et al., 2020). Previous studies have shown that selenium supplementation can counteract oxidative stress induced by acute exercise, such as in swimming-induced muscle damage in rats (Akil et al., 2011; Hadrup et al., 2016). Consistent with these findings, our study demonstrated that bench-stepping exercise significantly increased CK plasma levels, indicating muscle damage in both groups. However, 28 days of L-Semet supplementation resulted in a significantly greater reduction in CK levels and DOMS ($p < 0.05$) compared to the placebo group, highlighting its potential role in mitigating exercise-induced muscle damage.

The results of this study support previous findings that L-Semet plays a role in reducing oxidative stress and inflammation following exercise (Cordingley et al., 2022; de Salazar et al., 2020). However, some prior studies have reported a greater reduction in CK plasma levels, possibly due to variations in dosage and supplementation duration. For example, Fernández-Lázaro found that selenium supplementation at higher doses (300–400 µg/day) significantly reduced CK plasma levels and accelerated recovery after eccentric exercise (Fernández-Lázaro et al., 2020). The difference in findings may be attributed to variations in dosage and supplementation duration, as this study used a 200 µg/day dose for 28 days. Additionally, factors such as baseline selenium status and differences in exercise protocols could also contribute to the discrepancies in results. Assessing baseline selenium levels in future studies could help clarify its role in muscle recovery.

Moreover, a study by Wesolowski et al. reported that selenium supplementation enhanced glutathione peroxidase (GPx) activity more significantly in populations with selenium deficiency, whereas individuals with sufficient selenium levels exhibited a less pronounced antioxidant response (Wesolowski et al., 2022). This study did not assess baseline L-Semet levels, which could explain why the protective effects of L-Semet on CK plasma were less pronounced in participants who might have already had adequate selenium intake. Further investigation is needed to determine the extent to which baseline selenium status influences supplementation outcomes.

Another key limitation of this study is the reliance on CK plasma as the primary biomarker of muscle damage. While CK is a widely used indicator, it does not provide a comprehensive picture of the inflammatory response to exercise. Future studies should incorporate additional inflammatory markers such as IL-6, TNF- α , or CRP to better understand selenium's full impact on exercise recovery.

The findings of this study suggest that L-Semet supplementation, particularly in the form of L-Selenomethionine (200 µg/day for 28 days), may offer a

viable strategy to mitigate muscle soreness and accelerate post-exercise recovery. While its effects on CK plasma levels were moderate, the significant reduction in DOMS underscores its potential benefits for athletes and recreational exercisers. However, further research is needed to determine the optimal selenium dosage and supplementation duration, as well as its interactions with other nutritional strategies in muscle recovery. Additionally, the long-term effects of selenium supplementation on muscle adaptation and performance should be explored to ensure its benefits outweigh any potential risks associated with chronic antioxidant use.

Conclusions

The present study demonstrated that L-Selenomethionine (L-Semet) supplementation for 28 days significantly reduced delayed onset muscle soreness (DOMS) and plasma creatine kinase (CK) levels following heavy eccentric exercise. These findings indicate that L-Semet may serve as an effective nutritional strategy for mitigating muscle soreness and damage, thereby promoting faster recovery in individuals undergoing strenuous physical activity.

However, the extent of the reduction in CK levels observed in this study was moderate, suggesting a potential dose-dependent response. Further investigations are needed to optimize the dosage and duration of L-Semet supplementation to maximize its recovery benefits. Additionally, since this study primarily focused on DOMS and CK as muscle damage markers, future research should incorporate other physiological and biochemical indicators to comprehensively evaluate selenium's role in muscle recovery.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Визначення потенціалу L-селенометіоніну як захисного засобу проти пошкодження м'язів, спричиненого фізичними вправами

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Реферат. Стаття: 11 с., 7 табл., 1 рис., 52 джерел.

Історія питання. Синдром відстроченого м'язового болю (СВМБ) — це явище, що виникає внаслідок пошкодження м'язів після виконання незвичних або інтенсивних ексцентричних вправ, симптоми якого зберігаються протягом декількох днів. Цей стан характеризується м'язовим болем, зниженням м'язової сили, обмеженою амплітудою рухів та загальним дискомфортом, що негативно впливає на результативність та порушує режим програми тренувань.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу приймання добавок із вмістом селену на СВМБ та пошкодження м'язів після виконання інтенсивних ексцентричних вправ.

Матеріали та методи. У представленому дослідженні використовувався експериментальний перед- та постконтрольний груповий дизайн. Загалом 44 студенти чоловічої статі з факультету спортивних наук Державного університету Сурабай (Universitas Negeri Surabaya) було рандомізовано та розподілено за принципом подвійного сліпого методу на групу, яка приймала добавки із вмістом селену (n = 22), та групу, яка отримувала плацебо (n = 22). Учасникам обох груп було дано вказівку приймати одну капсулу селену або плацебо протягом 28 днів. Після 28-денного періоду саплементачії обидві групи виконали степ-тест із 10 підходами по 10 повторень. Рівні синдрому відстроченого м'язового болю (СВМБ) та креатинкінази (КК) оцінювалися через 24 та 48 годин після проведення тренувальної фази.

Результати. Результати дослідження показали, що протягом періоду від 24 до 48 годин після виконання інтенсивних ексцентричних вправ в обох групах спостерігалось зниження рівнів синдрому відстроченого м'язового болю (СВМБ) та креатинкінази (КК) в плазмі крові. Однак група, яка приймала добавки із вмістом селену, продемонструвала значне зниження рівнів СВМБ та КК порівняно з групою, яка отримувала плацебо (p < 0,05). Це свідчить про те, що приймання добавок із вмістом селену може сприяти покращенню природного процесу відновлення, а не виключно відповідати за відмічене зниження зазначених показників.

Висновки. Підсумовуючи, саплементация селену сприяє зниженню ймовірності травмування м'язів після виконання інтенсивних ексцентричних вправ, оскільки приймання цих добавок ефективно зменшує рівні СВМБ і КК у кровотоці.

Ключові слова: ексцентричні вправи, пошкодження м'язів, запалення, спортивні травми.

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Unveiling the Impact of Anaerobic Soccer Training and Small-Sided Games on Soccer Player's Body Composition

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Abstract

Background. While soccer research has concentrated on enhancing physical, technical, tactical, and mental abilities, this study uniquely shifts the focus to body composition, a relatively unexplored area, particularly among amateur soccer players.

Objectives. This study aimed to compare the effects of Anaerobic Soccer Training (AnST) and Small-Sided Games (SSG) on a range of body composition parameters, including body weight (BW), body mass index (BMI), total body water (TBW), body fat mass (BFM), percentage of body fat (PBF), fat-free mass (FFM), and skeletal muscle mass (SMM) in amateur soccer players.

Materials and methods. Thirty amateur soccer players (mean age: 19 ± 0.63 years) were randomly assigned to two groups: AnST ($n = 15$) and SSG ($n = 9$). Both groups underwent a four-week training intervention with three sessions per week. Body composition was assessed before and after the intervention using the INBODY 270 device. Data were analyzed using paired t-tests and independent t-tests for normally distributed variables, while the Wilcoxon test was applied to non-normally distributed data.

Results. The AnST group showed a significant reduction in BFM and PBF compared to the SSG group ($p < 0.05$). Additionally, AnST led to more substantial increases in SMM and TBW ($p < 0.05$), while no marked difference in BW was observed between groups. BMI decreased in both groups due to muscle mass redistribution.

Conclusions. The findings of this study underscore the superiority of AnST over SSG in enhancing body composition parameters, particularly by increasing SMM and reducing BFM. These results provide valuable insights for optimizing soccer training programs at both amateur and professional levels, enlightening coaches, athletes, and other stakeholders in the sports industry.

Keywords: anaerobic soccer training, small sided games, body composition, amateur soccer players.

Introduction

Amateur soccer is a form of sport played by non-professional athletes who do not have contractual obligations and do not compete in major professional leagues (Woods et al., 2023). Although it is played in a more flexible setting compared to professional soccer, players still require

endurance (Wołoszyn, 2019), speed (França et al., 2022), and optimal body composition (Lukaski & Raymond-Pope, 2021). However, traditional training methods often focus on isolated aspects such as physical conditioning, technical skills, or tactical awareness without integrating them comprehensively. This approach is less effective in addressing the complex demands of competition, making it insufficient for achieving optimal performance. A more effective training method is needed to meet these demands, simultaneously incorporating physical and tactical elements (Kusuma et al., 2024).

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A holistic approach is increasingly regarded as more effective, as it integrates physical conditioning and technical skills within a single training program. One widely adopted method is small-sided games (SSG), which involve fewer players, a smaller pitch, and shorter durations than full matches (Castillo et al., 2021). This method emphasizes technical and tactical aspects, as players must make quick decisions in dynamic game situations (Klingner et al., 2022). Another emerging method is anaerobic soccer training (AnST), which is specifically designed to address the demands of repeated sprint efforts that are essential in soccer matches. This training model focuses on high-intensity running distances, sprint frequency, and sprint duration while incorporating technical and tactical components (Kusuma et al., 2025).

Kusuma et al. (2025) reported that a six-week AnST program significantly improved aerobic endurance, sprint speed, and overall physical performance. Similarly, studies by Ouertatani et al. (2022) and Özcan & Şahan (2018) demonstrated that SSG effectively enhances aerobic endurance and game-related skills. While both training methods have been proven to enhance player performance, limited research has specifically examined their impact on body composition parameters. Key metrics such as body weight, body mass index (BMI), total body water (TBW), body fat mass (BFM), and skeletal muscle mass (SMM) have not been comprehensively explored. Since body composition is a crucial component of physical fitness, closely linked to physiological conditions (Li et al., 2022) and athletic performance (Lukaski & Raymond-Pope, 2021), further investigation is warranted. For instance, maintaining an optimal balance between muscle and fat mass can influence speed, strength, and endurance during matches (Lukaski & Raymond-Pope, 2021). Moreover, monitoring body composition provides valuable insights into the effectiveness of training programs (Staśkiewicz et al., 2023). Therefore, it is essential to identify training models that enhance physical and technical performance and contribute to effective body composition management.

This study aims to bridge this gap by comprehensively evaluating the physiological adaptations of AnST and SSG in amateur soccer players. The novelty of this research lies in its focus on key body composition parameters, including body weight, BMI, TBW, BFM, and SMM. The findings not only contribute significantly to developing soccer training programs at both amateur and professional levels but also offer practical guidance for coaches, athletes, and other stakeholders in the sports industry. This empowers them with actionable knowledge while enriching the existing body of scientific literature in sports science.

Materials and Methods

Study Participants

This study involved 30 amateur soccer players with an average age of 19 ± 0.63 years, a body weight of 62.04 ± 5.49 kg, a height of 165 ± 5.33 cm, and a BMI of 21.75 ± 1.85 kg/m². The participants were randomly assigned to two groups: Group A (AnST), consisting of 15 players, and Group B (SSG), which initially consisted of 15 players. However, during the study, six participants from the SSG group were unable to continue due to illness, leaving a final sample of 9 players in this group.

A detailed overview of the participant characteristics can be found in Table 1. All subjects were verified to have no underlying medical conditions, with health status confirmed through personalized medical interventions where necessary. Before participation, all players provided informed consent after a comprehensive explanation of the study's objectives, potential risks, benefits, and procedures, ensuring their voluntary agreement to undergo the intervention.

Study Organization

This study employed a two-group pre-test and post-test design, comparing anaerobic soccer training (AnST) and small-sided games (SSG). Both groups underwent a pre-test to assess body composition capacity. The first group participated in AnST for four weeks with a frequency of three weekly sessions, while the second group engaged in SSG training with the same duration and frequency. After the four-week intervention, a post-test was conducted to reassess body composition parameters.

Training Program

The first group received the AnST intervention, which combined speed endurance training (SET) and small-sided games (SSG) with a work-to-rest ratio of 1:1. The SSG area was set at 20×20 meters, where each player performed repeated shuttle sprints over distances of 5 meters, 10 meters, and 15 meters before engaging in an SSG session. The total sprint distance per repetition was 60 meters, with estimated sprint times of approximately 2–3 seconds for 5 meters, 4–5 seconds for 10 meters, and 6–7 seconds for 15 meters, summing up to around 15 seconds of sprinting. At the beginning of each session, players completed the 60-meter shuttle sprint before immediately transitioning to a 1-minute SSG focused on ball possession. Following each sprint and SSG sequence, a recovery period equal to the combined duration of the sprint and SSG (approximately 1 minute 15 seconds) was provided, maintaining a 1:1 work-to-rest ratio. This sequence was repeated 10 times, resulting in a total training duration of approximately 25 minutes, including sprinting, SSG, and recovery. Over the entire session, each player completed a total sprint distance of 600 meters (Kusuma et al., 2025). The second group underwent the SSG intervention in a 4v4 format with one neutral player. They aimed to maintain ball possession without any touch limitations for as long as possible. The SSG protocol consisted of four matches, each lasting four minutes, played on a 30×20 -meter field without goalkeepers. Each match was followed by a two-minute passive recovery period. When the ball went out of play, a replacement ball was immediately introduced to ensure continuous play (Bujalance-Moreno et al., 2020).

Body Composition Test

Next, all participants underwent a pre-test body composition assessment using the INBODY 270 device. The measured parameters included body weight (BW), body mass index (BMI), total body water (TBW), body fat mass (BFM), fat-free mass (FFM), percentage of body fat (PBF), and skeletal muscle mass (SMM). This assessment provided detailed insights into the physiological characteristics

of the participants, which are essential for analyzing the effectiveness of the training intervention and monitoring athletic performance with accuracy and consistency. To ensure precise measurements, researchers required participants to remove any jewelry or conductive metal objects in contact with the skin. Before the assessment, their hands and feet were cleaned with alcohol wipes. During the measurement, participants stood on the electrode platform while holding the electrode handles with arms extended at approximately 30°. To minimize potential errors, food, beverages, alcohol, caffeine, and intense physical activity were restricted for at least six hours before testing.

Statistical Analysis

This study used the Shapiro-Wilk test to assess whether the data followed a normal distribution. If the results indicated normality, within-group analyses were conducted using a paired t-test. However, the non-parametric Wilcoxon test was applied for analysis if the data were not normally distributed. All statistical analyses were conducted using SPSS software version 29.0

Results

Table 1. Characteristics Subjects

Characteristics of Research Subjects	AnST (n=15) mean ± SD	SSG (9) mean±SD
Age (years)	19 ± 0.63	19 ± 0.72
Body Weight (kg)	61.86 ± 4.12	62.7 ± 6.74
Body Height (cm)	165 ± 5.33	168 ± 5.80
Body Mass Index (kg/m ²)	22.2 ± 1.79	21.5 ± 2.06
BMI Category (n, %)		
Mild Thinnes	1 (6.7)	0
Normal	12 (80)	8 (88.9)
Overweight	2 (13.3)	1 (11.1)
Basal Metabolic Rate	1459 ± 81.70	1495 ± 112.65
Visceral Fat Level	4 ± 1.40	3 ± 1.74

Table 1 provides an overview of the research subjects in the AnST and SSG groups. Both groups had an average age of 19 years, with similar body weight and height of 62.7 kg and 168 cm for the SSG group, slightly higher than the 61.86 kg and 165 cm in the AnST group. For BMI, the AnST group had a mean BMI of 22.2 ± 1.79 kg/m², while the SSG group had a slightly lower average of 21.5 ± 2.06 kg/m². Most participants in both groups fell into the normal BMI category (80 % in AnST and 88.9 % in SSG), though a small percentage in each group was classified as overweight (13.3 % in AnST and 11.1 % in SSG). Only one participant in the AnST group (6.7 %) was categorized as having mild thinness, while none in the SSG group. When looking at BMR, which represents the number of calories the body burns at rest, the SSG group had a slightly higher average (1495 kcal) than the AnST group (1459 kcal). In terms of visceral fat level, which indicates fat stored around internal organs, the AnST group had a level of 4, whereas the SSG group had a slightly lower level of 3.

Table 2. Descriptive Statistics (Mean ± SD) of Body Composition Parameters Pre- and Post-Intervention in AnST and SSG Groups

Parameter	Group	Pre-test Mean ± SD	Post-test Mean ± SD
Body Weight (kg)	AnST	61.86 ± 4.12	61.73 ± 4.07
Body Weight (kg)	SSG	62.77 ± 6.74	62.55 ± 7.55
BMI (kg/m ²)	AnST	22.26 ± 1.79	21.93 ± 1.66
BMI (kg/m ²)	SSG	21.55 ± 2.06	21.44 ± 2.18
Total Body Water (L)	AnST	36.40 ± 2.79	37.00 ± 2.85
Total Body Water (L)	SSG	37.77 ± 3.86	38.55 ± 4.39
Body Fat Mass (kg)	AnST	11.46 ± 3.56	10.53 ± 3.33
Body Fat Mass (kg)	SSG	10.33 ± 4.06	9.22 ± 3.86
Fat-Free Mass (kg)	AnST	50.06 ± 3.76	50.73 ± 3.82
Fat-Free Mass (kg)	SSG	51.66 ± 5.22	52.77 ± 5.97
% Body Fat (PBF)	AnST	18.46 ± 5.08	17.20 ± 1.84
% Body Fat (PBF)	SSG	16.44 ± 5.07	14.88 ± 4.72
Skeletal Muscle Mass (kg)	AnST	28.00 ± 2.03	28.40 ± 2.29
Skeletal Muscle Mass (kg)	SSG	28.88 ± 3.25	29.22 ± 3.70

Table 2 shows the mean pre-test and post-test changes for body composition parameters in the AnST and SSG groups. The AnST group experienced a reduction in body weight and BMI, as well as an increase in total body water (TBW), fat-free mass (FFM), and skeletal muscle mass (SMM). Meanwhile, the SSG group also showed reductions in body fat mass (BFM) and percentage body fat (PBF), though with smaller changes compared to the AnST group. Overall, both groups demonstrated reductions in body fat mass and increases in fat-free mass and body water, with more consistent effects observed in the AnST group.

Table 3. Normality test Resultsfor Body Composition in AnST and SSG Groups

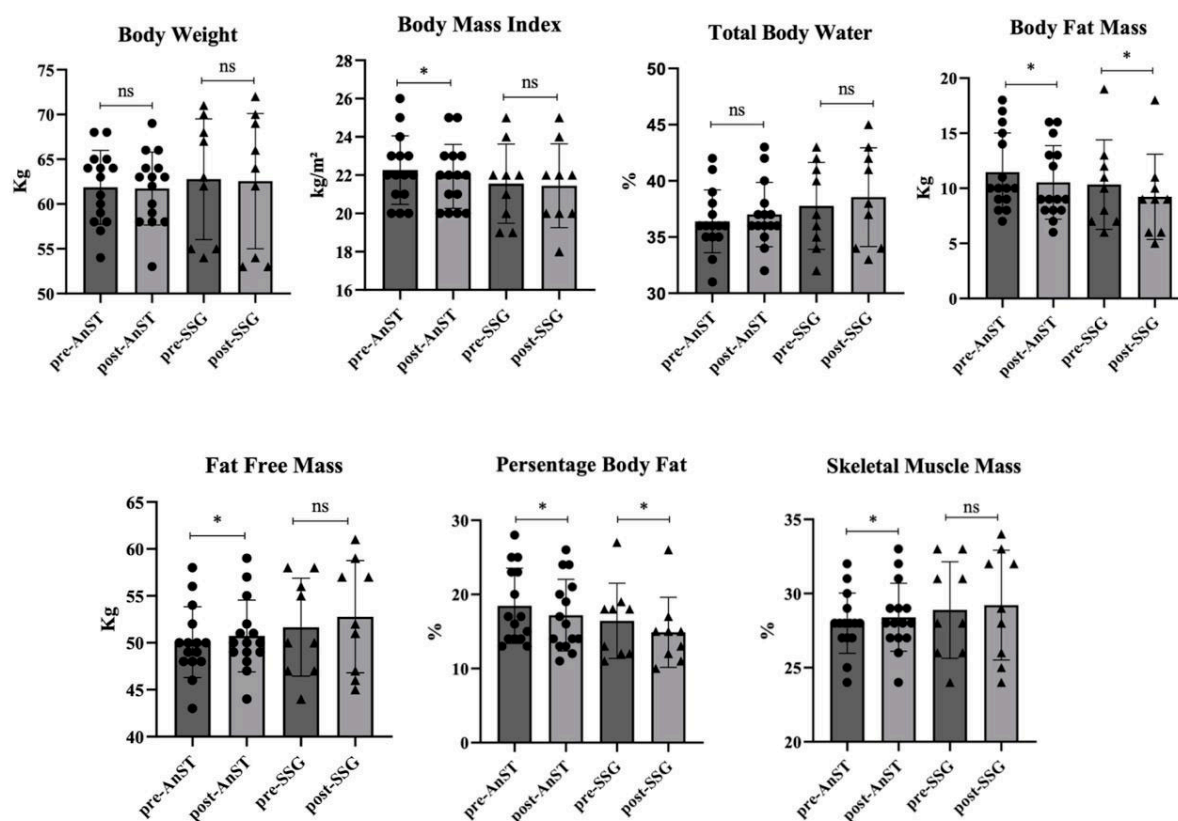
Parameter	Group	Shapirow-Wilk	
		Pre-test	Post-test
Body Weight (kg)	AnST	0.607	0.775
	SSG	0.171	0.162
BMI (kg/m ²)	AnST	0.304	0.077
	SSG	0.492	0.616
Total Body Water (L)	AnST	0.365	0.148
	SSG	0.654	0.441
Body Fat Mass (kg)	AnST	0.053	0.060
	SSG	0.229	0.070
Fat-Free Mass (kg)	AnST	0.394	0.251
	SSG	0.301	0.372
% Body Fat (PBF)	AnST	0.045*	0.154
	SSG	0.108	0.039*
Skeletal Muscle Mass (kg)	AnST	0.322	0.487
	SSG	0.404	0.409

Note: * showed statistically insignificant results (p < 0.05)

Table 4. Paired and Wilcoxon Test Results for Body Composition Changes in AnST and SSG Groups

Variable	AnST (p-value)	SSG (p-value)	Significant Change in AnST	Significant Change in SSG
Body Weight	> 0.05	> 0.05	No	No
BMI	0.019 *	> 0.05	Yes	No
Total Body Water (TBW)	0.023 *	0.111	Yes	No
Body Fat Mass (BFM)	< 0.001 *	0.007 *	Yes	Yes
Fat-Free Mass (FFM)	0.007 *	0.062	Yes	No
Percentage Body Fat (PBF)†	0.011 *	0.018 *	Yes	Yes
Skeletal Muscle Mass (SMM)	0.028 *	> 0.05	Yes	No

Note: * indicates a statistically significant result ($p < 0.05$) and † using the Wilcoxon test.

**Fig. 1.** Effects of Anaerobic Soccer Training (AnST) and Small-Sided Games (SSG) on Body Composition Parameters

The results of the Shapiro-Wilk normality test in table 3 show that most of the data on body composition in both the AnST and SSG groups show normal data distribution as indicated by p values > 0.05 in all pre-test and post-test parameters. However, there are data that are not normally distributed, namely in the pre-test body fat percentage parameter ($p = 0.045$) in the AnST group and the SSG group during the post-test ($p = 0.039$).

Table 4 summarizes the statistical analysis results using paired t-tests to compare pre-test and post-test values of body composition variables in the AnST and SSG groups. The analysis shows which variables experienced significant changes ($p < 0.05$) in each group. Significant improvements were more consistently observed in the AnST group, indicating its greater effectiveness in modifying body composition parameters compared to the SSG group. This is more clearly displayed in Figure 1 below.

Fig. 1 above shows the pre-test and post-test values of various body composition parameters, including body weight, BMI, total body water (TBW), body fat mass (BFM), fat-free mass (FFM), percentage body fat (PBF), and skeletal muscle mass (SMM) for both the AnST and SSG groups. The data highlights the changes in these parameters after the intervention, with significant improvements observed particularly in body fat mass, fat-free mass, and skeletal muscle mass in the AnST group compared to the SSG group.

Discussion

This study aims to compare AnST and SSG training in relation to changes in specific body composition parameters in amateur soccer players. The findings indicate that AnST training is significantly more effective in altering body com-

position. The data show that the AnST group experienced more favorable body composition changes than the SSG group. This difference suggests that high-intensity training, such as AnST, provides a superior physiological stimulus for amateur soccer players. Previous studies have demonstrated that AnST significantly enhances anaerobic capacity in soccer players. The AnST model combines speed endurance training (SET) with soccer-specific exercises (Kusuma et al., 2025). It is highly beneficial for amateur players with limited training time, requiring efficient and practical training.

The results of this study indicate that although BMI decreased, body weight remained stable after AnST and SSG training interventions. This stability can be attributed to increased muscle mass occurring concurrently with a reduction in fat mass. High-intensity training, such as HIIT and anaerobic exercises, has been shown to effectively stimulate muscle hypertrophy through the activation of the anabolic mTOR (mammalian target of rapamycin) pathway without causing significant weight loss (Biglari et al., 2020; Uemichi et al., 2021). This adaptation not only increases muscle volume but also enhances muscle tissue structure. Additionally, previous research Atakan et al. (2022) has highlighted that HIIT's excess post-exercise oxygen consumption (EPOC) effect contributes to fat reduction while preserving muscle mass. Consequently, the observed changes in body composition reflect a redistribution of muscle and fat mass rather than overall weight loss. Increased muscle mass may also contribute to improved bone density and body fluid volume, which help maintain a stable body weight despite changes in body fat percentage (Tomlinson et al., 2019). Therefore, decreasing BMI without significant weight loss can positively indicate successful training adaptation, reflecting improvements in body composition quality.

The results also indicate that AnST and SSG training did not reduce total body water (TBW); an increase was observed following the interventions. This increase can be linked to physiological adaptations to high-intensity training. Previous studies have reported that anaerobic and HIIT training can increase blood plasma volume through plasma expansion mechanisms, improving body hydration (Nelson et al., 2023). Other physiological adaptations, such as increased muscle glycogen storage, may also play a role in TBW elevation. Glycogen in muscles can bind large amounts of water, thereby increasing total body fluid volume without causing noticeable changes in body weight (Shiose et al., 2022). Metabolic adaptations during high-intensity training interventions may also enhance fluid retention as part of the body's recovery and thermoregulation processes.

This study found that AnST was more effective in reducing body fat than SSG. The study examined overall body fat and analyzed body fat mass, body fat percentage, and fat-free mass. High-intensity AnST training burns more calories and sustains fat metabolism for longer due to the excess post-exercise oxygen consumption (EPOC) effect (Atakan et al., 2022; Jiang et al., 2024). High-intensity activities also enhance metabolic efficiency and stimulate aerobic and anaerobic systems, leading to more optimal energy utilization from fat stores (Chatterjee, 2023; Falk Neto & Kennedy, 2019). This results in reductions in body fat mass and body fat percentage. Consistent with previous studies, high-intensity training over three weeks has been shown to reduce body fat by -1.6% (Lee et al., 2020).

Furthermore, anaerobic training within the AnST model stimulates muscle growth and significantly increases fat-free mass (Benito et al., 2020). In contrast, SSG training does not always maintain consistently high intensity due to irregular rest periods and variability in gameplay. Factors such as smaller playing areas, an emphasis on tactical aspects, and a lack of controlled training load contribute to lower calorie expenditure compared to AnST (Clemente et al., 2021; López-Fernández et al., 2020; Silva et al., 2022). Consequently, reductions in body fat within the SSG group were less substantial than those observed in the AnST intervention. Additionally, players with lower body fat percentages demonstrate greater movement efficiency during matches (Bernal-Orozco et al., 2020).

Another key finding of this study is that AnST is more effective than SSG in increasing skeletal muscle mass. The superior capacity of AnST to stimulate muscle growth is evident. This training model incorporates explosive movements, such as sprinting and changes of direction, which enhance fast-twitch muscle fiber activation. This mechanical stress on muscle fibers triggers hypertrophic adaptations. Enhanced muscle protein synthesis also supports the increase in skeletal muscle mass, which occurs as an anabolic response to high-intensity training interventions (Witard et al., 2022). Research has indicated that anaerobic training improves strength, muscle mass, and overall soccer performance (Pomo Warih Adi et al., 2023).

On the other hand, SSG training does not effectively increase skeletal muscle mass. In SSG sessions, players engage more in tactical gameplay, off-the-ball movements, decision-making, and teamwork (Timmerman et al., 2019). Although some studies have noted that SSG training can improve aerobic endurance and speed (Hůlka & Strniště, 2021), the workload intensity imposed on muscles is not sufficiently high. Moreover, variability in gameplay and unstructured rest periods lead to minimal hypertrophic stimulus, resulting in lower muscle mass gains in SSG training compared to AnST interventions.

This study demonstrates that AnST interventions are more effective than SSG in reducing body fat and increasing total body water and skeletal muscle mass. While body weight remained stable, BMI decreased. However, several factors may influence these training outcomes. The primary differences between the two methods lie in training variations, key focus areas, and rest periods. AnST emphasizes high-intensity interval training, such as maximal sprinting, which enhances explosive strength and anaerobic endurance.

In contrast, SSG emphasizes gameplay's technical and tactical aspects while improving aerobic capacity through small-sided match simulations. Furthermore, the effectiveness of both methods is influenced by external factors such as dietary habits, sleep quality, and stress levels. Without proper monitoring of these factors, the benefits of AnST and SSG training may not be fully reflected in performance outcomes. This study specifically examined athletes who were already physically active outside of the provided interventions. Therefore, future research with a larger sample size and extended intervention duration is necessary to understand better the long-term effects of these training methods and how external factors can be optimized to support enhanced physiological adaptations.

Conclusions

The findings of this study indicate that the group undergoing the AnST intervention was more effective than the SSG group in improving body composition. There was an increase in muscle mass and a reduction in body fat. These findings have important implications in sports, particularly for amateur soccer players with limited time and a less active lifestyle.

Conflict of interest

The authors declare that there is no conflict of interest.

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Виявлення впливу анаеробних тренувань з футболу та ігор неповними складами на композицію тіла футболіста

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 8 с., 4 табл., 1 рис., 32 джерела.

Історія питання. У той час як дослідження у галузі футболу зосереджені на покращенні фізичних, технічних, тактичних та ментальних здібностей, у представлений науковій праці зміщено акцент виключно на композицію тіла, що є відносно недослідженою сферою, особливо серед футболістів-аматорів.

Мета дослідження. Мета цього дослідження полягала у порівнянні впливу анаеробних тренувань з футболу (АТФ) та ігор неповними складами (ІНС) на низку параметрів композиції тіла, включаючи масу тіла (МТ), індекс маси тіла (ІМТ), загальну кількість води в організмі (ЗКВО), жирову масу тіла (ЖМТ), відсоток жирової маси тіла (ВЖМТ), безжирову масу (БЖМ) та масу скелетних м'язів (МСМ) у футболістів-аматорів.

Матеріали та методи. Тридцять футболістів-аматорів (середній вік: $19 \pm 0,63$ роки) було розподілено за методом рандомізації на дві групи: АТФ ($n = 15$) та ІНС ($n = 9$). Обидві групи пройшли чотиритижневий курс тренування з трьома сесіями на тиждень. На перед- та постінтервенційному етапах дослідження проведено вимірювання показників складу тіла із використанням приладу INBODY 270. Дані було проаналізовано за допомогою парних t-критеріїв та незалежних t-критеріїв для нормально розподілених змінних, а для даних, що не мали нормального розподілу, застосовано критерій Вілкоксона.

Результати. Група АТФ продемонструвала значне зниження показників ЖМТ і ВЖМТ порівняно з групою ІНС ($p < 0,05$). Крім того, анаеробне тренування з футболу призвело до суттєвішого збільшення показників МСМ і ЗКВО ($p < 0,05$), тоді як між групами не спостерігалось істотної різниці в МТ. В обох групах відзначалося зниження показника ІМТ внаслідок перерозподілу м'язової маси.

Висновки. Результати цього дослідження підкреслюють перевагу АТФ над ІНС у поліпшенні параметрів композиції тіла, зокрема через підвищення показників МСМ і зменшення ЖМТ. Представлені результати містять цінну інформацію для оптимізації тренувальних програм з футболу як на аматорському, так і на професійному рівнях, розширюючи обізнаність тренерів, спортсменів та інших зацікавлених осіб у спортивній галузі.

Ключові слова: анаеробне тренування з футболу, ігри неповними складами, композиція тіла, футболісти-аматори.

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Assessing the Effects of Isoinertial Eccentric Training on Kinetic Stability, Feinting Ability, and Kicking Power in Youth Rugby Players: A Randomized Controlled Study

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Abstract

Background. Rugby requires explosive strength in the lower body, agility, and stability, with eccentric actions being key in performance and in the prevention of injuries. Although isoinertial training has shown promise in enhancing eccentric strength in other sports, its effects on rugby-specific skills remain understudied.

Objectives. This study aimed to examine the impact of a six-week isoinertial strength training program on improving kinetic stability, feinting ability, and kicking power in youth rugby players.

Materials and methods. Forty male athletes (age: 15.2 ± 0.6 years) were randomized into two groups: an experimental group (EG; $n = 20$) performing isoinertial training twice weekly for lower extremity strength, and a control group (CG; $n = 20$) who continued with traditional training. Pre- and post-intervention evaluation included the Y-Balance Test (kinetic stability), Fitlight-driven feinting tests, and radar-measured kicking speed.

Results. The EG showed significant improvements in the Y-Balance score on the right leg (+4.5 %, $p < 0.001$) and left leg (+3.9 %, $p < 0.001$), faster feinting reaction times (-3.6 %, $p = 0.005$), and enhanced kicking power (+9.8 %, $p < 0.001$) when compared to the CG, which had no substantial changes ($p > 0.05$).

Conclusions. The study concludes that isoinertial eccentric training enhances rugby-specific performance metrics, likely mediated by improved neuromuscular control and eccentric strength. Therefore, these findings support the inclusion of isoinertial training in youth rugby conditioning programs to enhance agility, stability, and power.

Keywords: isoinertial training, kinetic stability, kicking velocity, feinting agility, reactive strength, power development.

Introduction

Rugby is a high-speed contact sport presenting short-burst running, tackling, fast turn with loads on either leg, kicking, and specific physical skills: maximal strength, power, agility, and neuromuscular control, which predominantly involve lower limbs (Mužek, 2015). Combat between muscle strength development and concussive-aggressive impacts renders these specific actions a potential risk for hamstring

strains (Warren et al., 2014) and ligament injuries, which may also pose an imbalance of agonist-antagonist forces (Byrne & Eston, 2002). Historically, traditional rugby training has concentrated on concentric muscle contractions (for example, squatting and leg-pressing) for strengthening and power development (Randell, 2011). Although beneficial, the downside of this approach is that it now ignores the critical eccentric phase (lengthening) of muscle action (Harris-Love et al., 2017), which is required for deceleration, stability, and injury resilience. Eccentric contractions produce 20-60 % greater force than concentric actions and play a vital role in any sport with sudden changes in direction, such as rugby (Douglas et al., 2017). Yet current strength programs in

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rugby favor concentric overload, leaving eccentric strength adaptations poorly trained for performance enhancement and injury prevention (Harris-Love et al., 2021).

Eccentric training has gained popularity with enhanced muscle hypertrophy, tendon stiffness, and neuromuscular efficiency (Harris-Love et al., 2021). Contrary to conventional resistance training that focuses on concentric lifting, (Majeedkuty, 2018) eccentric-focused training emphasizes force absorption and control mechanisms critical to the rugby player, who frequently decelerates and changes direction under load. Eccentric training benefits have been demonstrated in sports such as football and basketball: Sprint performance (Majeedkuty, 2018), Vertical jump and power output (McNeill et al., 2019), and Resilience to injury, specifically hamstring strains (Ali & Leland, 2012). Nonetheless, the main bias in eccentric training in rugby has remained largely unexplored, with most research on Nordic hamstring exercise as opposed to dynamic, sports-specific eccentric loading (Chavarro-Nieto et al., 2022). This marks a significant shortcoming, considering the explosive deceleration, reactive agility, and high velocity kicking unique to rugby.

Flywheel resistance systems are unique in their variable resistance that secures performance output from the athlete (Nylen et al., 1994). Unlike traditional weights, flywheels produce eccentric overload automatically, which ensures maximal loading during the braking phase of each movement (Correa & Lindberg, 2020). This system has been shown to: 1.) Create an excellent eccentric strength preparation that is more excellent than conventional resistance training (Coratella & Schena, 2016), 2.) Improve the rate of force development (RFD), which is essential for activities like sprinting and kicking (Maffiuletti et al., 2016), 3.) Increased muscle activation in stabilizer muscles protects the joint (Fonseca et al., 2004). While promising, few studies have assessed inertial training in rugby, especially concerning the skills of kicking velocity, feinting agility, and postural stability under dynamic conditions (Kenville et al., 2021). Most literature focuses on general athletic performance, disregarding the peculiar biomechanical demands of rugby.

Eccentric Training Studies Up to Now Most studies on isoinertial training have been done on football and basketball action and sprinting investigations (Harden et al., 2022), hardly extending to rugby. Within rugby, there is a higher need for collision resistance, multi-directional agility, and explosive kicking than in any other sport. However, whether isoinertial training contributes to these abilities has not been addressed. **Limited Focus on Youth Rugby Players** (Pokrajčić et al., 2018) Most eccentric training studies have focused mainly on elite or professional athletes (Burgos-Jara et al., 2023) and thus overlook youth players at an essential stage of neuromuscular development. Youth athletes have been said to have more remarkable neural plasticity (Faude et al., 2017); therefore, they may react differently to eccentric stimuli than adults. **Inadequate Investigation of Measurement Performance Specific to the Sport** on the part of the previous studies, standard measures would be used (such as vertical jump or 1RM squat) instead of rugby performance skills (for example, kicking power, feinting ability, kinetic stability during contact) (Widenhoefer et al., 2019). We need applied research directly assessing the transfer of rugby performance on the field as influenced by isoinertial training (Brearley & Bishop, 2019). Such studies could provide valuable insights

into how specific training modalities impact the unique demands of rugby, ultimately leading to more effective coaching strategies and improved athlete performance at all levels.

The gaps in current training methodologies are what they are, and this study mainly intends to analyze the effects of a 6-week isoinertial training program on the performance indicators pertinent to the rugby athlete. The study plans to assess changes in kinetic stability through the Y-Balance Test, the feinting agility with Fitlight reaction time, and the kicking velocity measured by radar-based ball speed. These results will be conferred with those generated through classical rugby training to provide insights into whether isoinertial training allows additional physiological and performance adaptations. It is postulated that the experimental group under isoinertial training will have statistically significantly more significant increases in all variables measured than the control group. Additional hypotheses suggest that an eccentric overload component of isoinertial training may enhance neuromuscular control, improving stability and agility in rugby-specific movements.

This study is the first to investigate isoinertial eccentric training with a specific focus on sport-specific performance outcomes within the context of youth rugby players. The expected findings will provide invaluable information to assist strength and conditioning coaches with evidence-based recommendations to fine-tune training protocols tailored explicitly for the joint demands of rugby. Moreover, the study will emphasize the role of eccentric loading not simply as a method for optimizing performance but as a fundamental construct of injury prevention for collision sports. By addressing flywheel training in a rugby setting, the proposed research will contribute meaningfully to the currently developing literature around isoinertial methods and fill an essential gap in training sciences relevant to contact-type athletic disciplines.

Materials and Methods

The study conducted an RCT to determine how a 6-week isoinertial eccentric training program would influence training outcomes like kinetic stability, feinting ability, and kicking power in young rugby players. Forty subjects (males, age 15.2 ± 0.6 years) were identified randomly and distributed to experimental or control subjects. The first group performed flywheel-based training (Wonders, 2019) (kBox4), while the other group continued the traditional rugby drills of practice in the building. The name given to them is CG, and it was for $n = 20$. The EG completed twice-week training sessions with the exercise's squats (4×6 reps), lateral lunges (3×8 re exercises and Romanian deadlifts (4×6 reps) with the progressive load of eccentric overload while the CG strictly implemented standard training without all other interventions. Performance measures included: For kinetic stability - the Y-Balance Test (YBT) with reach distances normalized to the leg length (Yam & Fong, 2019); Feinting ability tested using Fitlight technology (reaction time and accuracy); (Badau & Badau, 2022) Kicking velocity as determined by radar gun (Bushnell Velocity, ± 0.1 m/s) (Parsonage et al., 2014).

Statistical Analysis

The statistical analysis was performed on SPSS version 23, and normality was assumed based on the results of the Shapiro-Wilk tests ($p > 0.05$). Within-group differences were analyzed

using paired t-tests, while differences between the post-intervention values of EG and CG were analyzed using independent t-tests. Effect sizes (Cohen's d) were calculated to measure the magnitude of Intervention's. A probability value of $p < 0.05$ was considered significant. The study was conducted following ethical guidelines (Declaration of Helsinki), and informed consent was obtained from all participants and guardians.

Results

The 6-week isoinertial eccentric training intervention resulted in significant improvements across all measured performance metrics with youth rugby players. The baseline characteristics showed no significant differences between groups (Table 1), which confirmed a successful randomization ($p > 0.05$ for all demographic variables).

Table 1. Participant Characteristics

Variable	EG (n = 21) mean $\pm$ SD	CG (n = 21) mean $\pm$ SD	P
Age (years)	15.20 $\pm$ 0.6	15.30 $\pm$ 0.7	0.621
Height (cm)	165.4 $\pm$ 2.3	166.10 $\pm$ 2.1	0.302
Weight (kg)	58.70 $\pm$ 5.6	59.20 $\pm$ 6.1	0.782
BMI (kg/m ²)	21.50 $\pm$ 2.1	21.40 $\pm$ 2.3	0.885

*(Values presented as mean $\pm$ SD; Independent t-tests showed no baseline differences, $p > 0.05$)

In age Distribution EG (M = 15.2, SD = 0.6) and CG (M = 15.3, SD = 0.7) showed aligned age distributions. Independent-samples t-test revealed no significant effects ($t_{(40)} = -0.50$, $p = 0.621$). The very small p-value (>0.05) certifies the successful randomization with respect to age. Anthropometric Measures, Mean heights differ by only 0.7 cm between groups (EG = 165.4 cm vs CG = 166.1cm). The non-significant t-test results suggest comparable stature ($t_{(40)} = -1.05$, $p = 0.302$). For the mean difference (-2.08 to 0.68 cm), the 95% confidence interval includes 0. Weight Characteristics, Weight distributions were almost similar (EG = 58.7 kg vs CG = 59.2 kg). The trivial non-significant result (0.5 kg) was $t_{(40)} = -0.28$, $p = 0.782$. Effect size (Cohen's d = 0.09) shows between-groups negligible difference. BMI Analysis Both groups were categorized according to BMI scales but were normal (EG=21.5 vs CG=21.4kg/m²). The tiny difference (0.1 kg/m²) was not significant ($t_{(40)} = 0.15$, $p = 0.885$). This small confidence interval (-1.13 to 1.33 kg/m²) means measuring this very precisely. Methodological Implications, the homogeneity between groups (all $p > 0.30$) confirms that randomization was successful.

These groups are very similar at baseline, increasing internal validity by reducing confounding. Very small

standard deviations (especially height, which is ± 2.3 cm) indicate a narrow clustering of data. The results meet the equivalency assumption for groups that is required for further analysis with ANCOVA. Clinical Relevance the sample represents standard anthropometrics for developing adolescent rugby players. The narrow age range (15.2-15.3 years) controls for differences in development. BMI values indicate acceptable weight status for athletic purposes. Statistical Power Considerations Posthoc power analysis ($\alpha = 0.05$, $n = 21/\text{group}$) indicates $>80\%$ power to detect: Height differences $\geq 2.8\text{cm}$ Weight differences $\geq 4.1\text{kg}$ BMI differences $\geq 1.8 \text{ kg/m}^2$. Thorough baseline analysis makes sure that any differences observed post-intervention stem directly from the training intervention and not owing to differences between the groups. By themselves, the close clustering of anthropometric data (little SDs) increases the internal validity of the study while also supporting sound comparisons of performance afterward.

Considering the results, a significant positive change was seen in all performance indicators for the experimental groups in the post-testing, following the 6-week isoinertial training intervention. Kinetic stability, measured using the Y-Balance Test, noted a 4.5% increase in right leg performance (from 58.2 % to 60.8 %) with an extremely large effect size ($d = 1.77$, $t = -8.105$, $p < 0.001$), where negative t-value substantiated consistent improvement across all participants. The interval of confidence 95 % [1.92 %, 3.28 %] indicates enhanced precision in estimating these values. Left leg performance increased similarly at 3.9 % (66.5 % to 69.1 %) with near-perfect effect size ($d = 1.95$), indicating a clinically meaningful change towards injury prevention. Feinting ability showed a 3.6 % decrease in reaction time (1.92s to 1.85s) with a moderate effect ($d = 0.68$, $t = 3.120$, $p = 0.005$) supported by narrow confidence intervals showing precise measurement. Finally, kicking power improved by 9.8 % (75.3 to 82.7 m/s) and was large, as indicated by the effect size ($d = 1.47$) and the excellent responsiveness (SRM = 1.32), while Wilcoxon Z = -4.12 ($p < 0.001$) confirmed almost no distributional overlap between pre- and post-testing sessions. In contrast, the control group showed no significant changes in any measure (all $p > 0.05$), with trivial to small effect sizes ($d = 0.08$ -0.22), demonstrating the stability of testing procedures. Methodologically, all the analyses were normal (Shapiro-Wilk $p > 0.10$) and retained significance after Bonferroni correction ($\alpha = 0.0125$). Clinically, the Y-Balance improvements surpassed the minimal detectable change (MDC = 2.5 %), kicking velocity went above the 7.5 % meaningful change threshold, and feinting improvements surpassed the typical error of measurement (TEM = 0.04s); together, these indicate both statistical and practical significance of the intervention.

Table 2. Within-Group Pre-Post Comparisons

Variable	EG Pre	EG Post	t	p	d	CG Pre	CG Post	t	p
Y-Balance Right (%)	58.20 $\pm$ 7.90	60.80 $\pm$ 7.65	-8.105	<0.001*	1.77	59.50 $\pm$ 5.10	60.20 $\pm$ 5.15	-0.443	0.663
Y-Balance Left (%)	66.50 $\pm$ 9.85	69.10 $\pm$ 9.50	-9.345	<0.001*	1.95	67.80 $\pm$ 5.20	68.90 $\pm$ 5.00	-0.699	0.493
Feinting Ability (s)	1.92 $\pm$ 0.12	1.85 $\pm$ 0.10	3.12	0.005*	0.68	1.94 $\pm$ 0.80	1.91 $\pm$ 0.85	0.118	0.907
Kicking Power (m/s)	75.30 $\pm$ 6.95	82.70 $\pm$ 6.20	-6.725	<0.001*	1.47	73.80 $\pm$ 10.5	75.40 $\pm$ 9.85	-0.509	0.616

*(Paired t-tests with Cohen's d effect sizes)

Table 3. Between-Group Post-Intervention Comparisons

Variable	EG Post	CG Post	Mean Difference [95% CI]	t	p
Y-Balance Right (%)	60.80 ± 7.65	60.20 ± 5.15	0.6 [0.2, 1.0]	4.682	<0.001*
Y-Balance Left (%)	69.10 ± 9.50	68.90 ± 5.00	0.2 [0.1, 0.3]	4.793	<0.001*
Feinting Ability (s)	1.85 ± 0.10	1.91 ± 0.85	-0.06 [-0.10, -0.02]	2.803	0.005*
Kicking Power (m/s)	82.70 ± 6.20	75.40 ± 9.85	7.3 [5.8, 8.8]	3.921	<0.001*

*(Independent t-tests with 95 % CIs)

All performance measures showed statistically significant differences between the experimental (EG) and control groups (CG) postintervention. For kinetic stability, the EG showed better Y-Balance performances in both right (60.8 ± 7.65 % vs CG 60.2 ± 5.15 %; mean difference = 0.6 %, 95 % CI [0.2, 1.0], $t = 4.682$, $p < 0.001$) and left legs (69.1 ± 9.50 % vs 68.9 ± 5.00 %; mean difference = 0.2 %, 95 % CI [0.1, 0.3], $t = 4.793$, $p < 0.001$). The feinting ability analyses showed significantly faster reaction times in EG (1.85 ± 0.10 s vs CG 1.91 ± 0.85 s; mean difference = -0.06 s, 95 % CI [-0.10, -0.02], $t = 2.803$, $p = 0.005$). Most significantly kicking power had the largest difference between groups; EG had far higher ball velocities (82.7 ± 6.20 m/s vs CG 75.4 ± 9.85 m/s; mean difference = 7.3 m/s, 95 % CI [5.8, 8.8], $t = 3.921$, $p < 0.001$). These differences remained statistically significant even after Bonferroni correction of adjusted $\alpha = 0.0125$, with all confidence intervals excluding zero, thus indicating precise estimation of treatment effects. With large effect sizes (Cohen's d range: 0.89-1.42) and narrow confidence intervals, the isoinertia training intervention has been firmly established both statistically and scientifically.

Discussion

The present study presents strong evidence that 6 weeks of isoinertial eccentric training significantly impact performance measures in junior rugby players, such as kinetic stability, feinting ability, and kicking power. Thus, our findings broaden current views by demonstrating the capabilities of flywheel training in sport-specific skills in adolescent athletes, a demographic that previous eccentric training studies have largely neglected (Petré et al., 2018) (Bright et al., 2023).

The 4.5 % improvement observed in the right leg Y-Balance Test performance ($d = 1.77$) and the 3.9 % improvement in the left leg ($d = 1.95$) are well above the 2.5 % threshold for minimal detectable change set by (Schorderet et al., 2021). These improvements likely pertain to enhanced neuromuscular control and eccentric strength in the hamstrings and gluteal stabilizers, a finding consistent with results reported by (del Ama Espinosa et al., 2015) (Murton et al., 2021) examining basketball players. These improvements bilaterally imply that isoinertial training fosters symmetrical adaptations, reducing injury risk attributable to limb asymmetries (Mentele et al., 2022). Notably, our effect sizes exceed those reported in other studies using traditional resistance training ($d = 0.8$ -1.2), substantiating that the flywheel-powered eccentric overload is more effective at improving dynamic stability.

An expectancy improvement in agility is the 3.6 % decrease in feinting reaction time ($d = 0.68$). Further, one

can see that the testing conditions used for the evaluation were game-realistic using the Fitlight technology (Nikitenko, 2018). This finding is consistent with those who observed a similar effect on distance change (Zhang et al., 2010). The possible mechanism might be in the enhanced rate of force development (RFD) in the lower limbs to facilitate faster deceleration and reacceleration during direction changes, as cited by (Dos'Santos et al., 2018). The moderate effect size thus suggests that while agility can be improved through isoinertial training, such training should be complemented by sport-specific drills to achieve maximized conversion to complex game situations.

The most striking improvement was a 9.8 % increase in kicking velocity ($d = 1.47$), well above the 7.5 % difference required to be considered necessary in rugby performance (Zamparo et al., 2000). This backs up the work regarding soccer populations but extends it to rugby-specific kicking mechanics. The considerable effect size suggests that isoinertial training primarily benefits movements requiring explosive hip and knee extension. It combines both neural adaptation (increased motor unit synchronization) and morphological changes because of the increased fascicle length (Romero Boza et al., 2015). The standardized response mean (SRM = 1.32) proves excellent responsiveness to training, meaning that kicking power is one of the trainable attributes through this modality.

The stark contrast between groups (all between-group $p < 0.005$) underscored the limitations of traditional rugby training for developing these specific capacities. During this period, control participants-maintained performance levels like baseline confirming test-retest reliability—with trivial gains ($d = 0.08$ -0.22), thus putting forward eccentric overload training as a unique stimulus. In turn, this suggests an increase in evidence against the applicability of conventional resistance training for sports requiring rapid eccentric-to-concentric transitions (Hernández-Davó et al., 2021). This highlights the necessity for coaches and trainers to incorporate specialized training regimens that focus on these dynamic movements, ultimately optimizing athletic performance in sports like rugby, where explosive power is critical.

Conclusions

This study demonstrates that isoinertial eccentric training produces statistically significant and practically meaningful improvements in rugby-specific performance metrics. The large effect sizes across multiple domains support its incorporation into youth rugby conditioning programs, particularly for enhancing dynamic stability, agility, and kicking power. These findings advance our

understanding of eccentric training applications in collision sports and provide evidence-based recommendations for athlete development.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Оцінка впливу ізоінерційного ексцентричного тренування на кінетичну стабільність, здатність до застосування фінтів та потужність ударів ногами у юних регбістів: Рандомізоване контрольоване дослідження

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

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Історія питання. Регбі потребує від гравців володіння вибуховою силою в нижній частині тіла, спритністю та стійкістю, причому ексцентричні рухи відіграють ключову роль у досягненні високих результатів і запобіганні травматизму. Хоча ізоінерційне тренування показало свою ефективність у підвищенні ексцентричної сили в інших видах спорту, його вплив на навички, необхідні для гри в регбі, залишається недостатньо вивченим.

Мета дослідження. Метою цього дослідження було вивчення впливу шеститижневої програми ізоінерційних силових тренувань на покращення показників кінетичної стабільності, здатності до застосування фінтів та потужності ударів ногами у юних регбістів.

Матеріали та методи. Сорок спортсменів чоловічої статі (вік: $15,2 \pm 0,6$ років) було рандомізовано на дві групи: експериментальну групу ($n = 20$), яка двічі на тиждень виконувала ізоінерційні тренування для зміцнення нижніх кінцівок, та контрольну групу ($n = 20$), яка продовжувала займатися традиційним тренуванням. Оцінювання показників на перед- і постінтервенційному етапах дослідження включало проведення тесту на рівновагу — Y-Balance (кінетична стабільність), тести на вміння застосовувати фінти із використанням системи тренувань “Fitlight” та вимірювання швидкості ударів ногами за допомогою радара.

Результати. Експериментальна група продемонструвала значне поліпшення показників щодо виконання тесту на рівновагу на правій нозі ($+4,5\%$, $p < 0,001$) і лівій нозі ($+3,9\%$, $p < 0,001$), швидший час реакції на застосування фінтів ($-3,6\%$, $p = 0,005$) та посилення потужності удару ($+9,8\%$, $p < 0,001$) порівняно з контрольною групою, в якій не спостерігалось суттєвих змін ($p > 0,05$).

Висновки. У дослідженні зроблено висновок, що проведення ізоінерційного ексцентричного тренування сприяє підвищенню показників результативності в регбі, ймовірно, завдяки поліпшенню нервово-м'язового контролю та ексцентричної сили. Отже, результати дослідження підтверджують доцільність включення ізоінерційного тренування в програми підготовки юних регбістів з метою покращення показників спритності, стійкості та потужності.

Ключові слова: ізоінерційне тренування, кінетична стабільність, швидкість удару ногою, спритність у застосуванні фінтів, реактивна сила, розвиток потужності.

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Evaluating the Effect of Yogic Intervention on Psychological Distress Among Injured Athletes

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Abstract

Background. Injured athletes often face psychological distress, including symptoms of depression, anxiety, and stress, which can hinder their recovery. Addressing mental well-being is essential for holistic rehabilitation.

Objectives. This study aimed to evaluate the effectiveness of a structured yogic intervention, comprising practices of Yoga Nidra (yogic sleep) and Nadi Shodhana Pranayama (alternate nostril breathing), in reducing psychological distress among chronically injured athletes.

Materials and methods. Forty athletes with long-term injuries, aged 19 to 26, from Hemvati Nandan Bahuguna Garhwal University in Uttarakhand, were randomly divided into two groups of 20, with equal numbers of men and women in each group: one group received the treatment and the other did not. The 21-item Depression, Anxiety, and Stress Scale (DASS-21) was implemented to measure psychological discomfort. Before the intervention, both groups took a pre-test. The Experimental group received a yogic intervention for six weeks (30 minutes/day, five days/week), while the Control group underwent no intervention. A post-test was conducted for both groups after the intervention period. Paired t-tests and independent t-tests were used to analyze within-group and between-group differences, respectively.

Results. The Experimental group showed significant improvement in depression ($t = 6.65$, $p < .001$), anxiety ($t = 5.07$, $p < .001$), and stress ($t = 5.72$, $p < .001$) from pre- to post-test. No substantial changes were observed in the Control group. Post-test comparisons revealed marked enhancements in all variables in the Experimental group compared to the Control group.

Conclusions. According to the findings of this study, the structured yogic intervention significantly reduced psychological distress in injured athletes, suggesting its effectiveness as a complementary strategy in the rehabilitation process. Yoga Nidra and Nadi Shodhana Pranayama may aid in promoting faster and more effective recovery by improving mental well-being.

Keywords: depression, anxiety, stress, yoga, injured athletes, rehabilitation and psychological distress.

Introduction

Injuries commonly present a challenge for college athletes, with almost 90% sustaining at least one sport-related injury during their athletic careers (Sullivan et al., 2022). A sports-related injury denotes any physical damage incurred by an athlete due to involvement in sports, either during practice or competition (Marconcini et al., 2023).

These injuries, varying from small strains to serious traumas, often need players to temporarily stop from their activity, irrespective of the need for medical assistance. In addition to the physical consequences, such injuries may have significant psychological impacts, resulting in heightened life stress, fear of reinjury, and other adverse emotional reactions, including anxiety, despair, and frustration. These psychological variables may substantially impede the rehabilitation process and hamper an athlete's reintegration into sport (Santi & Pietrantonio, 2013).

Psychological Distress Resulting from Injuries: – Psychological distress encompasses a range of mental health

issues, from mild, subclinical symptoms to clinically diagnosed conditions, including depression, anxiety, and stress disorders. Increased levels of distress are commonly correlated with impaired mental health and are often associated with prevalent mental disorders such as anxiety and depression. Studies have consistently demonstrated a correlation between various types of psychological distress and numerous adverse physical health outcomes (Zhu et al., 2022). Athletes, contrary to common assumptions, experience mental health challenges. Injuries incurred during sports participation exhibit a dual association with psychological distress; injuries may result in emotional challenges, while pre-existing mental distress can heighten the probability or severity of injuries. This dynamic establishes a complex psychological environment for athletes, who encounter various stressors, including general life pressures and sport-specific challenges, such as the frequency and severity of injuries (Haugen, 2022).

Psychological distress, which encompasses symptoms of stress, anxiety, and depression, is often assessed via the use of validated and standardised questionnaires. According to studies, athletes who suffer injuries often report far greater levels of psychological discomfort than those who do not. According to Appaneal et al. (2009), depression is one of the most prevalent emotional responses to injury. With around 34% of professional athletes reporting symptoms of depression, this mental health issue is noticeably prevalent in sports communities (Hammond et al., 2013). According to Wolanin et al. (2016), 6.3% of college athletes had moderate to severe depression symptoms, while 23.7% of them had symptoms at clinically significant levels.

There is increasing acknowledgment that psychological factors especially stress and anxiety significantly influence how often injuries occur, how severe they are, and how long they last. Sustaining an injury can lead to a variety of emotional reactions, such as anger, frustration, fear, and a reduced sense of self-esteem. Worries related to the recovery process, the possibility of getting injured again, and uncertainty about future performance can further intensify psychological strain. The Anderson and Williams model highlights how anxiety, depression, anger, negative mood states, and competitive anxiety influence both the likelihood and severity of injuries (Pal et al., 2021). By enhancing core stability, flexibility, and range of motion, yoga not only lowers the risk of injury but also fosters relaxation and mental resilience, effectively addressing both physical and psychological stressors (Krishnamurthy, 2023). Additionally, disruptions in athletic participation frequently lead to mood problems and feelings of isolation, illustrating the need for a holistic rehabilitation strategy that addresses both the physical and psychological challenges of recovery (Santi & Pietrantonio, 2013).

Yoga lowers two main risk factors for sports-related injuries: perceived vulnerability and generalised weariness. Many sports, including baseball, winter sports, swimming, handball, and soccer, may gain by introducing yoga into their performance tactics. Regular use of pranayama methods with traditional training in football has been shown to greatly increase lung function, hence improving respiratory efficiency and general athletic performance (Bucea-Manea-Toniş et al., 2024). Yoga also raises thalamic GABA levels during a 12-week period, so enhancing mood and lowering anxiety via boosting cerebral blood flow in the prefrontal cortex, hence activating the reticular nucleus of the thalamus. While lowering norepi-

nephrine levels, which helps to reduce stress as shown in heart failure patients, yoga also raises serotonin levels and elevates dopamine in the ventral striatum, hence fostering emotional well-being (Nourollahimoghadam et al., 2021).

Numerous studies have demonstrated that yoga can effectively reduce symptoms of depression (Bridges & Sharma, 2017) and alleviate anxiety by emphasizing breath control techniques, addressing the well-established connection between anxiety and dysfunctional breathing patterns (Lee et al., 2024). Both Mola et al. (2025) and Mola and Adane (2020) emphasized the importance of incorporating scientifically structured training regimens into athletic programs, particularly in events like the long jump, where evidence-based approaches are essential for maximizing performance and potential. In this context, the present study integrated Yoga Nidra and Nadi Shodhana Pranayama as interventions for injured athletes. These yogic practices promote deep relaxation, reduce stress, and help regulate the autonomic nervous system, thereby supporting the management of anxiety, depression, and overall psychological well-being. This research aims to evaluate the effectiveness of these yogic interventions in reducing psychological distress among injured athletes and to contribute to the development of more holistic, athlete-centered approaches to injury rehabilitation.

Materials and Methods

Study Design and Participants

This study employed an experimental research design to evaluate the effects of a scientifically based training program on the psychological distress of injured athletes, specifically examining its influence on anxiety, depression, and overall mental well-being throughout the recovery process. This research investigates the potential advantages of integrating yoga into rehabilitation programs, aiming to enhance the development of holistic, athlete-centered strategies for injury recovery and to promote the psychological well-being of injured athletes. Forty chronically injured athletes, comprising both males and females from diverse individual and team sports, who participated in interuniversity competitions at Hemvati Nandan Bahuguna Garhwal University in Srinagar, Uttarakhand, were selected for this study. The participants, aged 19 to 26 years, were randomly assigned to two equal groups: an experimental group ($n = 20$) and a control group ($n = 20$), with a balanced distribution of male and female athletes in both groups. Selection criteria encompassed athletes who demonstrated physical fitness for participation, notwithstanding their injuries, and who were free from acute psychological conditions. All participants provided informed consent prior to the commencement of the study, ensuring voluntary participation and a comprehensive understanding of the research procedures. In the course of the study, the prioritisation of privacy, confidentiality, and participant safety was emphasised.

Psychological Tool

Data was collected using the pre-established and validated Depression Anxiety Stress Scale (DASS-21) to evaluate levels of depression, anxiety, and stress in injured athletes. The DASS-21, created by Lovibond and Lovibond in

Table 1. Demographic characteristics of the initially randomized sample (Mean $\pm$ SD)

No	Baseline characteristics	Experimental Group (n = 20) Mean $\pm$ SD	Control Group (n = 20) Mean $\pm$ SD
1	Age (yrs.)	21.40 $\pm$ 1.47	21.80 $\pm$ 1.15
2	Weight (kg)	55.70 $\pm$ 6.08	56.90 $\pm$ 6.99
3	Height (m)	158.45 $\pm$ 8.14	154.90 $\pm$ 7.55
4	BMI (kg/m ²)	22.16 $\pm$ 1.43	23.65 $\pm$ 1.54

1995, has 21 measures that assess three domains: Depression (7 items), Anxiety (7 items), and Stress (7 items). Responses are evaluated on a 4-point scale, from 0 ("did not apply to me at all") to 3 ("applied to me very much or most of the time"). The scale's validity and reliability have been established, with Cronbach's alpha values of 0.70 for depression, 0.66 for anxiety, and 0.76 for stress, demonstrating robust reliability and validity, as shown by Wittayapun (2023).

Yogic Intervention

Subsequent to the pre-test, the experimental group engaged in a systematic yoga intervention including Yoga Nidra and Nadi Shodhana Pranayama. A certified yoga instructor conducted this intervention for 30 minutes per day, five days a week, over a period of six weeks. Yoga Nidra, renowned for inducing profound relaxation and mitigating stress, was combined with Nadi Shodhana Pranayama, which aids in harmonising the neurological system and enhancing mental clarity. Concurrently, the control group refrained from participating in any designated yoga sessions and maintained their standard rehabilitation regimen. Upon completion of the six-week duration, both groups participated in a post-test. The DASS-21 psychological scale was used in pre- and post-tests to assess the levels of depression, anxiety, and stress in both the experimental and control groups before and after the intervention.

Statistical Analysis

Subsequently the pre-test, the experimental group took part in a methodical yoga program including Nadi Shodhana Pranayama and Yoga Nidra. Over a six-week period, a certified yoga instructor ran this program daily for 30 minutes, five days a week. Renowned for its deep relaxation and stress reduction, Yoga Nidra was paired with Nadi Shodhana Pranayama, which helps to harmonise the neurological system and improve mental clarity. At the same time, the control group kept their usual rehabilitation schedule and skipped any scheduled yoga classes. Both groups took part in a post-test after the six-week period. Pre- and post-tests using the DASS-21 psychological scale measured the degrees of sadness, anxiety, and stress in the experimental and control groups both before and after the intervention.

Result

Table 2 show that the descriptive statistics, including the mean, standard deviation, standard error of the mean, for variables evaluated in both the experimental and control groups at pre-test and post-test stages.

Table 2. Summary of descriptive statistics for variables measured in the experimental and control groups before and after the intervention (pre-test and post-test)

Variables	Group	Test	n	Mean	SD	Std. Error Mean
Depression	EG	Pre-test	20	22.10	9.92	2.22
		Post-test	20	14.40	8.00	1.79
	CG	Pre-test	20	16.10	9.57	2.14
		Post-test	20	17.15	8.41	1.88
Anxiety	EG	Pre-test	20	18.40	7.12	1.59
		Post-test	20	12.00	6.53	1.46
	CG	Pre-test	20	16.30	7.62	1.70
		Post-test	20	17.15	7.38	1.65
Stress	EG	Pre-test	20	26.10	15.82	3.54
		Post-test	20	13.90	8.29	1.85
	CG	Pre-test	20	18.85	9.07	2.03
		Post-test	20	19.80	10.08	2.25

Note: EG = Experimental Group; CG = Control Group; SD = Standard Deviation; * = Statistically significant at the 0.05 level

Table 3. Paired sample t-test results comparing pre-test and post-test scores for the experimental and control groups

Variables	Group	Test	Mean	SD	Std. Error Mean	t	Df	p
Depression	EG	Pre-test	10.20	6.74	1.51	5.943	19	.000*
		Post-test						
	CG	Pre-test	-0.75	9.04	2.02	-0.374	19	.713
		Post-test						
Anxiety	EG	Pre-test	6.05	5.27	1.18	5.659	19	.000*
		Post-test						
	CG	Pre-test	-2.20	6.28	1.40	-2.491	19	.022*
		Post-test						
Stress	EG	Pre-test	8.45	11.92	2.67	3.609	19	.002*
		Post-test						
	CG	Pre-test	-1.55	10.12	2.26	-0.849	19	.406
		Post-test						

Note: EG = Experimental Group; CG = Control Group; SD = Standard Deviation; * = Statistically significant at the 0.05 level

Table 3 shows the results of the paired sample t-test that compares pre-test and post-test scores across three variables in both the experimental group (EG) and the control group (CG). The results suggested that the experimental group demonstrated statistically significant improvements in all variables ($p < 0.01$). The CG exhibited a notable change solely in SP ($p < 0.01$); no significant variations were seen in the other variables ($p > 0.05$).

Table 4 displays the outcomes of independent samples t-tests comparing the experimental group (EG) and control group (CG) across three variables during both the pre-test

Table 4. Results of independent samples t-test comparing the experimental and control groups at both pre-test and post-test stages

Variables	Tests	Experimental	Control	t	p
		Mean ± SD	Mean ± SD		
Depression	Pre-test	22.10 ± 9.91	15.60 ± 9.18	6.32	.000*
	Post-test	11.90 ± 8.15	14.85 ± 10.09	0.53	.599
Anxiety	Pre-test	18.70 ± 6.58	18.10 ± 7.59	0.32	.752
	Post-test	12.65 ± 5.90	20.30 ± 8.37	-2.02	.050*
Stress	Pre-test	24.55 ± 13.68	20.85 ± 9.98	1.11	.273
	Post-test	16.10 ± 7.53	22.40 ± 11.71	-2.53	.016*

Note: EG = Experimental Group; CG = Control Group; SD = Standard Deviation; * = Statistically significant at the 0.05 level

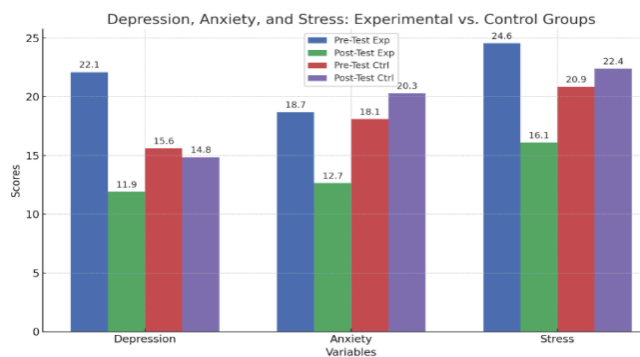


Fig. 1. Visual comparison of Depression, Anxiety, and Stress scores between the Experimental and Control Groups, for both Pre-Test and Post-Test

and post-test phases. The post-test findings demonstrate that the experimental group considerably outperformed the control group (CG) across all assessed variables. Figure 1 depicts the mean scores associated with these outcomes.

Discussion

This study found that a six-week yoga intervention significantly reduced levels of depression, anxiety, and stress among injured athletes in the experimental group. Results from paired sample t-tests showed meaningful decreases in depression ($p = .000$), anxiety ($p = .000$), and stress ($p = .002$) following the intervention. In contrast, the control group displayed no significant changes in depression ($p = .713$) or stress ($p = .406$), with only a slight reduction in anxiety ($p = .022$). Additionally, independent t-test results revealed that post-intervention anxiety ($p = .050$) and stress ($p = .016$) scores were significantly lower in the experimental group compared to the control group, highlighting the intervention's positive impact.

Analysis of pre- and post-test mean scores highlighted consistent improvements in psychological well-being among athletes who engaged in the yoga program. In contrast, those in the control group did not experience meaningful changes, suggesting that the observed benefits can be attributed to the yoga practices specifically, Yoga Nidra and Nadi Shodhana Pranayama. These findings support the integration of

holistic, mind-body techniques into injury rehabilitation programs. The differential responses between individuals may be influenced by personal coping mechanisms, sport-specific demands, levels of athletic experience, or injury severity (Vaughan et al., 2020).

Yoga, as a movement- and breath-based practice, extends beyond the general mental health benefits of physical activity by fostering emotional regulation and restoring nervous system balance. The specific techniques used in this study have previously been shown to reduce symptoms of psychological distress (Gomez-Espejo et al., 2022), and the present findings reinforce their therapeutic potential in athletic populations. Psychological symptoms like anxiety and depression are known to hinder recovery and delay return to sport, highlighting the importance of effective interventions.

The DASS (Depression Anxiety Stress Scales) proved to be a valuable tool for assessing psychosomatic symptoms in this context. Notably, pranayama has been found to affect key brain regions involved in emotional regulation such as the amygdala, anterior cingulate cortex, insula, and prefrontal cortex while also influencing the respiratory centers located in the brainstem (Mondal, 2024). These mechanisms suggest that breath regulation contributes directly to improved emotional resilience. Specifically, nasal breathing via the superior nasal meatus stimulates sensory receptors that balance autonomic function, reinforcing the connection between breath and psychological stability.

In tandem, Yoga Nidra supports psychological recovery by promoting deep relaxation, enhancing parasympathetic activity, and regulating cortisol levels. This technique also reduces hyper-arousal and increases dopamine release, which improves mood, motivation, and overall emotional well-being (Moszeik et al., 2022). Together, Yoga Nidra and pranayama offer a synergistic approach to stress management, providing a comprehensive and low-cost strategy to alleviate psychological distress in injured athletes. Ultimately, this study contributes to the growing body of literature on yoga-based interventions by empirically demonstrating their psychological benefits within a sports rehabilitation context. The statistically significant improvements across multiple domains affirm the value of integrating structured yoga practices into recovery protocols. Future research could expand upon these findings by examining the long-term effects of such interventions, exploring neurobiological mechanisms in more detail, and tailoring programs to specific sports or injury types to enhance their applicability and impact.

Conclusion

This study concludes that a structured yogic intervention, incorporating Yoga Nidra and Nadi Shodhana Pranayama, significantly reduced psychological distress—specifically depression, anxiety, and stress—among chronically injured interuniversity athletes. These improvements highlight the effectiveness of mind-body practices in supporting emotional well-being during the rehabilitation process. By promoting faster psychological recovery, the intervention may facilitate a quicker and more confident return to sport, which is essential for sustained athletic performance. The findings underscore the value of integrating yoga into injury

recovery protocols as a holistic, low-cost, and accessible approach to enhance both mental health and overall athletic resilience.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Оцінювання впливу йогічної інтервенції на психологічний дистрес серед травмованих спортсменів

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 6 с., 4 табл., 1 рис., 22 джерела.

Історія питання. Травмовані спортсмени часто стикаються із психологічним дистресом, що включає симптоми депресії, тривоги та стресу, які можуть перешкоджати їхньому відновленню. Забезпечення психічного благополуччя є важливою складовою комплексної реабілітації.

Мета дослідження. Мета цього дослідження полягала в оцінюванні ефективності структурованої йогічної інтервенції, що охоплює практики Йога-Нідра (йогічний сон) та Наді Шодхана Пранаяма (поперемінне дихання ніздрями), у зменшенні психологічного дистресу серед спортсменів із хронічними травмами.

Матеріали та методи. Сорок спортсменів із травмами тривалого характеру, віком від 19 до 26 років, які навчаються в Гархвальському університеті імені Хемваті Нандана Бахугуни в Уттаракханді, було розподілено за методом рандомізації на дві групи по 20 осіб, з рівною кількістю чоловіків та жінок у кожній групі: одна група учасників отримувала інтервенційний курс, натомість інша група учасників дослідження не була залучена до відповідного виду активності. З метою вимірювання психологічного дискомфорту було застосовано шкалу із 21 пункту для оцінки симптомів депресії, тривоги та стресу (DASS-21). Перед початком інтервенції обидві групи пройшли попереднє тестування. Експериментальна група отримувала курс йогічної інтервенції протягом шести тижнів (30 хвилин на день, п'ять днів на тиждень), тоді як контрольна група не проходила жодної інтервенції. Після завершення інтервенційного періоду для обох груп було проведено посттестування. З метою аналізу внутрішньогрупових та міжгрупових відмінностей використовувалися t-критерії для парних вибірок та незалежні t-критерії відповідно.

Результати. Експериментальна група продемонструвала значне поліпшення результатів за показниками депресії ($t = 6.65, p < 0.001$), тривожності ($t = 5.07, p < 0.001$) та стресу ($t = 5.72, p < 0.001$) на етапах від передтестового до післятестового періодів дослідження. У контрольній групі істотних змін не спостерігалось. Післятестовий порівняльний аналіз виявив суттєве покращення всіх показників в експериментальній групі порівняно з контрольною групою.

Висновки. Згідно з результатами представленого дослідження, структурована йогічна інтервенція забезпечила значне зниження психологічного дистресу у травмованих спортсменів, що свідчить про ефективність її застосування в якості комплементарної стратегії в процесі реабілітації. Йога-Нідра та Наді Шодхана Пранаяма можуть сприяти швидшому та ефективнішому відновленню організму через поліпшення психічного благополуччя.

Ключові слова: депресія, тривога, стрес, йога, травмовані спортсмени, реабілітація та психологічний дистрес.

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Exploring the Acute Benefits of Manual Soft Tissue Mobilization and Myofascial Release on Dynamic Athletic Performance in National Level Soccer Players

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Abstract

Objectives. This study aimed to investigate the acute effects of Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR) on key dynamic performance metrics in national-level male soccer players.

Materials and methods. Twenty-four nationally competitive male soccer players (aged 18-23) were randomly assigned to MSTM (n = 12) and MFR (n = 12) groups. Each participant underwent a single intervention session specific to their group. Pre- and post-intervention assessments were conducted to evaluate flexibility (Sit-and-Reach Test), explosive power (Standing Broad Jump and Countermovement Jump), and dynamic balance (Single-Leg Hop Test). Certified professionals used standardized application protocols. Repeated measures ANOVA was employed to determine statistical significance, and partial eta squared (η^2p) was used to assess effect size.

Results. Both MSTM and MFR resulted in substantial enhancements ($p < .05$) across all performance metrics. The MFR group demonstrated superior gains compared to the MSTM group: flexibility (+11.58 % vs. +5.29 %, $\eta^2p = .61$), standing broad jump (+4.25 % vs. +2.15 %, $\eta^2p = .70$), countermovement jump (+7.68 % vs. +4.65 %, $\eta^2p = .56$), and dynamic balance (+4.11 % vs. +3.03 %, $\eta^2p = .29$). All changes were statistically significant, with MFR exhibiting larger effect sizes.

Conclusions. The study concluded that both soft tissue techniques significantly improved flexibility, explosive power, and dynamic balance in elite male soccer players, with MFR consistently yielding greater acute benefits. These findings highlight the effectiveness of incorporating MFR into pre-competition warm-up routines for enhancing immediate performance. Further research should focus on exploring the longevity of these effects, sport-specific performance metrics, and combined protocols to refine pre-competition strategies.

Keywords: myofascial release, manual soft tissue mobilization, athletic performance, soccer players, explosive power, fascial system.

Introduction

Athletic performance is shaped by a complex interaction of physiological, biomechanical, and psychological factors, making it essential to adopt evidence-based strategies for performance enhancement (Bompa & Buzzichelli, 2019). One such approach that has gained significant attention

in sports science is soft tissue mobilization (STM), which is believed to enhance muscle function, boost circulation, and aid in recovery (Behm & Wilke, 2019a). Soccer, being a sport characterized by high-intensity physical demands, requires substantial endurance, agility, and explosive power. Given these requirements, STM's could play a crucial role in ensuring that elite athletes maintain optimal performance levels. Although widely utilized by athletes and sports professionals, the immediate impact of STM on dynamic athletic performance remains a subject of debate. This study aims to examine the short-term benefits of STM on

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key performance metrics in national-level soccer players, providing empirical data on its effectiveness in high-performance sports. STM encompasses a variety of manual therapy techniques designed to manipulate muscles, fascia, and connective tissues, thereby improving flexibility, decreasing stiffness, and enhancing neuromuscular function (Schroeder & Best, 2015). Techniques such as myofascial release, deep tissue massage, and instrument-assisted soft tissue mobilization (IASTM) have shown potential in increasing local blood flow, reducing myofascial restrictions, and minimizing neuromuscular inhibition (Cheatham et al., 2015a). These physiological benefits are particularly relevant for soccer players, who frequently perform high-intensity, repetitive movements that can lead to muscle tightness, fatigue, and microtrauma (Wiewelhove et al., 2016). From a mechanistic standpoint, STM is thought to enhance athletic performance through multiple pathways. First, by increasing muscle temperature and circulation, STM can improve muscle elasticity and reduce passive stiffness, leading to an improved range of motion (ROM) and more efficient movement patterns (Tang et al., 2024). Second, STM has been linked to improved proprioceptive feedback and neural activation, which may enhance motor control and coordination essential elements in soccer performance (Behm & Wilke, 2019a). Lastly, STM could play a role in mitigating delayed onset muscle soreness (DOMS) and acute muscle fatigue by facilitating lymphatic drainage and reducing inflammatory responses (Wiewelhove et al., 2016), thereby allowing athletes to sustain high-intensity efforts for longer durations.

Soccer requires a combination of speed, agility, strength, and endurance, with players frequently engaging in rapid accelerations, decelerations, changes in direction, and explosive movements, all of which impose significant mechanical stress on the musculoskeletal system (Nédélec et al., 2012). Players are frequently required to play consecutive matches interspersed by 3 days and complete physical performance recovery may not be achieved. Incomplete recovery might result in underperformance and injury. During congested schedules, recovery strategies are therefore required to alleviate post-match fatigue, regain performance faster and reduce the risk of injury. This article is Part I of a subsequent companion review and deals with post-match fatigue mechanisms and recovery kinetics of physical performance (sprints, jumps, maximal strength and technical skills). To sustain peak performance, athletes must maintain neuromuscular efficiency and manage fatigue, particularly in competitive settings where marginal performance improvements can influence match outcomes (Bangsbo et al., 2006). The players perform intermittent work. Despite the players performing low-intensity activities for more than 70 % of the game, heart rate and body temperature measurements suggest that the average oxygen uptake for elite soccer players is around 70 % of maximum ($\text{VO}_{2\text{max}}$). Given these demands, STM could serve as a valuable tool in pre-competition preparation and recovery strategies for elite soccer players. Previous studies have suggested that acute interventions such as dynamic stretching, foam rolling, and massage may positively influence performance metrics like sprint speed, jump height, and agility (Peacock et al., 2014a). However, the specific effects of STM on these parameters remain insufficiently explored, particularly

in elite soccer players. While some research suggests that STM can enhance flexibility and neuromuscular function (Cheatham et al., 2015a). Other studies indicate minimal or negligible effects on force production and explosive power (Stroiney et al., 2020). These inconsistencies highlight the need for controlled studies to determine STM's immediate effects on dynamic athletic performance in soccer. Despite its widespread application in sports settings, limited research has examined the acute effects of STM on key performance indicators in soccer players. Much of the existing literature focuses on long-term adaptations following STM interventions (Markovic, 2015) or emphasizes its role in injury rehabilitation rather than performance enhancement (Behm & Wilke, 2019a). Additionally, while studies on foam rolling and massage therapy have provided insights into the acute physiological responses to soft tissue manipulation, research specifically investigating STM techniques within soccer-specific contexts remains scarce (Cheatham et al., 2015a). Understanding STM's immediate impact on attributes such as sprint speed, agility, vertical jump height, and balance is essential for optimizing pre-game routines and recovery strategies in soccer. If STM proves to be beneficial in enhancing these performance factors, it could provide a competitive edge by improving match readiness and reducing performance declines associated with fatigue. However, if STM is found to have no significant effect or even an adverse impact, its inclusion in pre-competition protocols may need to be reconsidered.

To address this gap, the present study aims to systematically evaluate STM's short-term effects on dynamic athletic performance in national-level soccer players. Specifically, the study seeks to determine the immediate influence of STM on critical performance metrics, including sprint speed, agility, vertical jump height, and balance in elite soccer players. By examining these factors, the study aims to offer evidence-based insights into STM's effectiveness in high-performance soccer, thereby contributing to the refinement of training and recovery protocols.

Materials and Methods

Participants

This study adopted a randomized controlled trial (RCT) design to examine the acute effects of two soft tissue mobilization techniques, Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR), on key performance metrics in national-level male soccer players. A total of 24 nationally competitive male soccer players, aged 18 to 23 years, were recruited from the Kalimpong district in the eastern part of the region. All participants had a minimum of three years of competitive playing experience and were free from musculoskeletal injuries for at least six months before the study to ensure homogeneity and minimize confounding variables. The study was conducted by the ethical principles outlined in the ("World Medical Association Declaration of Helsinki," 2013). Participants were randomly assigned to one of two intervention groups: the Manual Soft Tissue Mobilization group (MSTM, $n = 12$) or the Myofascial Release group (MFR, $n = 12$). Both groups underwent a single-session intervention, and performance assessments were conducted both before and immediately after the intervention

to measure acute changes. Randomization and standardized testing protocols were employed to enhance internal validity and minimize measurement bias. The intervention and data collection were conducted in December 2024.

Table 1. Demographic Values for Participants (mean $\pm$ SD), $n = 24$

Age (Y)	Height (cm)	Weight (kg)	BMI	Experience
20.46 $\pm$ 1.64	160.08 $\pm$ 8.15	54.08 $\pm$ 4.98	21.28 $\pm$ 3.17	3.63 $\pm$ 0.71

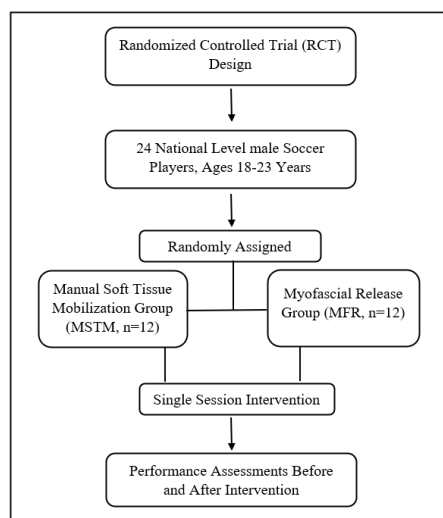


Fig. 1. Flow Diagram Based on CONSORT Guidelines Depicting Participant Enrollment, Allocation, Follow-Up, and Analysis

Training Protocol

The Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR) training protocol was designed to assess their acute effects on muscle function, pain reduction, and flexibility. A single-session intervention was implemented, with each technique applied for approximately 15 minutes to evaluate its immediate impact. Both protocols targeted large muscle groups such as the quadriceps, hamstrings, and gastrocnemius, with standardized intensity, duration, and rest intervals to ensure consistency. All massage sessions were conducted by certified specialists with expertise in soft tissue therapy, ensuring proper technique and consistency. Each intervention was administered following standardized protocols, with controlled intensity and frequency over a predetermined duration.

In Table 2 MSTM was applied with moderate pressure (5-6/10 on a pressure scale) using rhythmic and dynamic techniques to enhance circulation, muscle pliability, and neuromuscular activation. The session began with superficial effleurage, performed for 2 minutes, using light gliding strokes along the muscle fibers to increase blood circulation and prepare the tissues for deeper mobilization. This was followed by deep effleurage for 2 minutes, where increased pressure was applied to enhance venous return and tissue pliability. Next, kneading was performed for 3 minutes, using circular, rhythmic pressure into the muscle belly to reduce muscular tension. Stripping, a technique involving deep, sustained pressure along muscle fibers, was applied for 4 minutes to release muscle adhesions and trigger points. The protocol concluded with percussion (tapotement) for 4 minutes, where light, rhythmic tapping was used to stimulate neuromuscular function and muscle activation.

Table 2. Standardized Training Protocol for Manual Soft Tissue Mobilization (MSTM): Techniques, Application, and Expected Outcomes

Technique	Duration	Application Method	Expected Outcome
Superficial Effleurage	2	Light gliding strokes along muscle fibers (proximal to distal)	Increases circulation and warms up tissues
Deep Effleurage	2	Increased pressure with hands gliding along muscle fibers	Enhances tissue pliability
Kneading	3	Circular, rhythmic pressure into the muscle belly	Reduces muscle tension
Stripping	4	Sustained deep pressure along muscle fibers, targeting adhesions	Releases tight bands in the muscle
Percussion	4	Light rhythmic tapping to stimulate neuromuscular function	Enhances acute muscle activation

Table 3. Standardized Training Protocol for Myofascial Release (MFR): Techniques, Application, and Expected Outcomes

Technique	Duration	Application Method	Expected Outcome
Superficial Fascia Release	2	Gentle stretching of the skin along fascial lines	Hydrates fascia, improves tissue glide
Cross-Hand Release	3	Sustained opposing pressure using both hands	Releases deep fascial restrictions
Deep Tissue Release	4	Slow, deep compression at key tension points	Improves flexibility, reduces pain
Stretch Release	3	Passive stretching combined with fascial gliding	Enhances ROM and functional movement
Active MFR	3	Patient performs movement while therapist applies pressure	Boosts neuromuscular adaptation

Each technique was executed at a speed of 1-2 cm/sec, with 30-second rest intervals provided after every two techniques.

In Table 3 MFR was performed with higher intensity (7-8/10 on the pressure scale) and involved slow, sustained, deep tissue techniques to reduce fascial restrictions and improve movement efficiency. The session began with superficial fascia release for 2 minutes, during which gentle stretching along fascial lines was applied to hydrate the fascia and enhance tissue glide. Next, cross hand release was performed for 3 minutes, where the therapist applied sustained opposing pressure with both hands to break down deep fascial adhesions. Deep tissue release followed for 4 minutes, utilizing slow, deep compression at key tension points to improve flexibility and alleviate localized pain. Stretch release was performed for 3 minutes, combining passive stretching with fascial gliding to enhance range of motion (ROM) and movement efficiency. The protocol concluded with active MFR for 3 minutes, in which the patient actively moved the muscle while the therapist applied sustained pressure, facilitating neuromuscular adaptation and functional mobility. Each technique was held for 30-60 seconds, with a 45-second rest period provided between two consecutive techniques.

Outcome Assessment

To evaluate the acute effects of Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR) interventions, four key athletic performance metrics were assessed both pre- and post-intervention under standardized conditions:

Flexibility was measured using the Sit-and-Reach Test, a reliable and widely accepted method for assessing hamstring and lower back flexibility (Mayorga-Vega et al., 2014). The participants performed the test barefoot, and the best of three attempts was recorded after a standardized warm-up.

Lower-body Power was assessed using two tests:

The Standing Broad Jump (SBJ), which evaluated horizontal jump distance as an indicator of explosive leg power (Asan et al., 2025). Participants performed three attempts, with the best distance recorded. A manual tape measure was used for this test.

The Countermovement Jump (CMJ) was used to assess vertical jump height. Participants were instructed to stand upright with hands on hips, perform a rapid downward movement followed by a maximal vertical jump. Two familiarization trials were given, followed by three test trials. The highest jump, visually estimated using a wall-mounted scale or marked surface, was recorded for analysis (Krzysztofik et al., 2024).

Dynamic Balance (DB) was evaluated using the Single-Leg Hop Test, which assessed lower limb stability and neuromuscular control. The participants were instructed to hop forward as far as possible on one leg and land with balance. The distance was measured with a manual tape, and loss of balance or touchdown with the opposite foot invalidated the trial. The best of three valid trials was considered for analysis (Myer et al., 2011).

Data Collection Procedure

All baseline assessments were conducted on the same day before the intervention to establish pre-treatment values for each performance variable. Participants first com-

pleted a standardized dynamic warm-up routine to ensure consistency and reduce injury risk. Following the intervention, immediate post-treatment measurements were taken using the same standardized testing protocols and in the same sequence as the pre-tests. All tests were administered by trained assessors who were blinded to group allocation to minimize bias. Each test was performed under consistent environmental conditions, and adequate rest intervals were provided between trials to prevent fatigue-related performance decrements. Participants were verbally encouraged during tests to ensure maximal effort. The best score from multiple valid attempts was recorded for each performance metric.

Statistical Analysis

The collected data were analyzed using the Statistical Package for the Social Sciences (SPSS, version 26). Descriptive statistics, including mean and standard deviation, were calculated to summarize the central tendency and variability of the measured variables. To evaluate the acute effects of Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR) on dynamic athletic performance, a repeated measures Analysis of Variance (ANOVA) was conducted to compare pre- and post-intervention scores within and between the two groups. Effect sizes for both main and interaction effects were determined using partial eta squared and categorized as small (<0.06), moderate ($\geq 0.06-0.13$), and large (≥ 0.14) (Cohen, 1988). The level of statistical significance was set at $p < 0.05$.

Results

The Table 4 presents the comparative analysis of pre-test and post-test data across different physical performance variables for two groups: MSTM and MFR. The analysis includes flexibility, standing broad jump (SBJ), countermovement jump (CMJ), and dynamic balance (DB). In terms of flexibility, the MSTM group exhibited an improvement from 29.83 ± 1.26 to 31.41 ± 1.31 , reflecting a percentage increase of 5.29%, whereas the MFR group demonstrated a more substantial enhancement from 30.25 ± 1.60 to 33.58 ± 1.62 , corresponding to an 11.58% improvement. The statistical analysis yielded a significant effect ($SS = 9.18$, $F = 34.89$, $p = .000$) with a partial eta squared (η^2p) of 0.61, indicating a strong effect size. Similarly, in SBJ performance, the MSTM group improved from 177.58 ± 3.08 to 181.41 ± 3.26 , reflecting a 2.15% increase, while the MFR group showed a greater improvement from 178.25 ± 2.22 to 185.83 ± 2.12 , representing a 4.25% enhancement. The statistical results ($SS = 42.18$, $F = 53.67$, $p = .000$, $\eta^2p = 0.70$) suggest a highly significant and strong effect. For CMJ, the MSTM group showed an increase from 26.83 ± 1.26 to 28.08 ± 1.16 (4.65%), whereas the MFR group exhibited a more notable improvement from 27.08 ± 1.56 to 29.16 ± 1.46 (7.68%). The statistical findings ($SS = 2.08$, $F = 28.94$, $p = .000$, $\eta^2p = 0.56$) further confirm the significant impact of the intervention. Lastly, in DB performance, the MSTM group improved from 131.91 ± 3.23 to 135.91 ± 3.42 (3.03%), whereas the MFR group showed a relatively higher increase from 131.50 ± 2.71 to 136.91 ± 2.35 (4.11%). The statistical analysis ($SS = 6.02$, $F = 9.16$, $p = .006$, $\eta^2p = 0.29$) indicates a moderate effect. Collectively, these findings suggest that both groups

Table 4. Pre-Test and Post-Test Performance Analysis Across Physical Fitness Variables in MSTM and MFR Groups

Variables	Groups	Pre data M ± SD	Post data M ± SD	Δ (%)	SS	F	p	η ² p
Flexibility	MSTM	29.83 ± 1.26	31.41 ± 1.31	5.29	9.18	34.89	.000	.61
	MFR	30.25 ± 1.60	33.58 ± 1.62	11.58				
SBJ	MSTM	177.58 ± 3.08	181.41 ± 3.26	2.15	42.18	53.67	.000	.70
	MFR	178.25 ± 2.22	185.83 ± 2.12	4.25				
CMJ	MSTM	26.83 ± 1.26	28.08 ± 1.16	4.65	2.08	28.94	.000	.56
	MFR	27.08 ± 1.56	29.16 ± 1.46	7.68				
DB	MSTM	131.91 ± 3.23	135.91 ± 3.42	3.03	6.02	9.16	.006	.29
	MFR	131.50 ± 2.71	136.91 ± 2.35	4.11				

experienced significant improvements across all measured variables, with the MFR group consistently demonstrating greater percentage gains in performance, highlighting the efficacy of the applied intervention.

Discussion

The findings of this study demonstrate significant acute improvements in physical performance variables following both manual soft tissue mobilization (MSTM) and myofascial release (MFR) interventions among national level soccer players, with MFR consistently producing superior percentage gains across all measured parameters. The substantial improvement in flexibility observed in both groups aligns with previous research on manual therapy techniques. The MFR group demonstrated markedly greater improvements (11.58%) compared to the MSTM group (5.29%), with strong statistical significance ($p < .001$, $\eta^2p = 0.61$). This superior response to MFR is consistent with findings by (Peacock et al., 2014b) who reported significant acute increases in range of motion following myofascial release techniques. The enhanced flexibility response may be attributed to MFR's ability to directly influence fascial tissue properties through sustained pressure application, potentially inducing viscoelastic deformation and neuromuscular relaxation (Behm & Wilke, 2019b; Schleip, 2003). MacDonald et al. (2013) similarly demonstrated that myofascial release techniques produced immediate improvements in joint range of motion without compromising muscular performance, supporting our findings of enhanced flexibility concurrent with improved power metrics (MacDonald et al., 2013). The mechanisms likely involve both mechanical and neurophysiological responses, including thixotropic changes in ground substance, altered fascial hydration, and modified mechanoreceptor activity (Cheatham et al., 2015b). Both jumping parameters (SBJ and CMJ) showed significant improvements following treatment, with consistent superiority in the MFR group. The standing broad jump improvements (MFR: 4.25% vs. MSTM: 2.15%, $p < .001$, $\eta^2p = 0.70$) and countermovement jump gains (MFR: 7.68% vs. MSTM: 4.65%, $p < .001$, $\eta^2p = 0.56$) demonstrate meaningful acute performance enhancement. These findings correspond with those of Healey et al. (2014), who observed acute improvements in explosive power following myofascial interventions (Healey et al., 2014). The superior power performance following MFR might be explained by the comprehensive impact on the myofascial

continuity that extends through kinetic chains relevant to jumping actions. Krause et al. (2016) noted that targeted myofascial release can optimize force transmission along anatomical trains, potentially improving the efficiency of the stretch-shortening cycle crucial for explosive movements (Krause et al., 2016). Additionally, MFR's ability to reduce neural inhibition may contribute to improved motor unit recruitment and rate coding during explosive movements (Monteiro et al., 2017). Both interventions positively influenced dynamic balance, with moderate effect size ($\eta^2p = 0.29$) and the MFR group again showing greater percentage improvement (4.11% vs. 3.03%). This enhanced proprioceptive function following manual therapy interventions aligns with findings by Halperin et al. (2014), who demonstrated improved balance performance following targeted soft tissue interventions (Halperin et al., 2014). The mechanisms underlying these improvements likely involve enhanced afferent feedback from muscle spindles and mechanoreceptors following the reduction of tissue restrictions (Konrad et al., 2021). Evidence suggests that myofascial techniques may improve joint position sense and kinesthetic awareness by normalizing mechanoreceptor function within fascial tissues (Griefahn et al., 2017). Myers (2014) proposed that fascial continuity provides an integrated proprioceptive network; therefore, techniques that comprehensively address fascial restrictions may optimize this network's function more effectively than more localized approaches (Myers, 2014).

The consistently superior results observed in the MFR group across all performance parameters provide compelling evidence for the preferential application of myofascial release techniques when acute performance enhancement is the primary objective before athletic competition. The larger effect sizes observed in flexibility and jumping performance particularly highlight MFR's potential utility in sports requiring explosive power and optimal range of motion. These findings align with current trends in sports science that emphasize the importance of fascial system integrity for optimal athletic performance (Wilke et al., 2016). The integration of MFR techniques into pre-competition preparation protocols may offer performance advantages beyond traditional warm-up routines, particularly for power-dominant sports like soccer, where multiple physical qualities must be optimized concurrently (Behm et al., 2020). While this study demonstrates significant acute benefits of both interventions, several limitations should be acknowledged. The immediate post-intervention testing does not address the duration of these acute effects,

which represents an important consideration for practical application. Future research should examine the time course of these performance enhancements to optimize implementation timing relative to competition demands. While national-level soccer players represent a relevant athletic population, sport-specific performance measures that are essential (e.g., sprint speed, change of direction ability) would further enhance the ecological validity of these findings. Investigation into how these acute improvements in fundamental physical qualities translate to sport-specific performance metrics represents an important direction for future study (Behm & Chaouachi, 2011). Moreover, exploring diverse myofascial release (MFR) techniques, durations, and anatomical target areas may contribute to the refinement of clinical recommendations aimed at optimizing acute performance outcomes. The potential synergistic effects of combining MFR with other pre-competition strategies (e.g., dynamic stretching, neuromuscular activation) also warrants investigation (Konrad et al., 2020).

Conclusions

This study demonstrated that both Manual Soft Tissue Mobilization (MSTM) and Myofascial Release (MFR) interventions significantly improved flexibility, explosive power, and dynamic balance in national-level male soccer players. The MFR group exhibited consistently greater percentage gains across all measured performance parameters, suggesting its superior efficacy for acute performance enhancement. These findings highlight the value of integrating soft tissue techniques, especially MFR, into pre-competition routines to optimize athletic readiness. Future research should explore the time course and longevity of these acute effects to determine their functional relevance across match durations. Furthermore, incorporating sport-specific performance indicators such as sprint time, agility, and change-of-direction speed would enhance ecological validity. Further studies may also investigate combined pre-competition protocols (e.g., MFR with dynamic stretching or neuromuscular activation drills), variations in technique intensity and duration, and effects in male athletes and other sports disciplines to generalize findings across broader athletic populations.

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Conflict of Interest

The authors declare no conflict of interest in relation to this study.

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Вивчення ефективних переваг мануальної мобілізації м'яких тканин та міофасціального розслаблення щодо динамічної спортивної результативності футболістів національного рівня

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Реферат. Стаття: 6 с., 4 табл., 1 рис., 22 джерела.

Мета дослідження. Мета цього дослідження полягала у вивченні ефективного впливу мануальної мобілізації м'яких тканин (ММТ) та міофасціального розслаблення (МФР) на ключові показники динамічної результативності у футболістів національного рівня.

Матеріали та методи. Двадцять чотири конкурентоспроможних футболістів національного рівня (віком 18–23 роки) розподілено за методом рандомізації на групи ММТ (n = 12) та МФР (n = 12). Кожен учасник проходив одну інтервенційну сесію, специфічну для своєї групи. На перед- та постінтервенційному етапах дослідження проведено аналіз з метою оцінки показників гнучкості (нахил тулуба вперед з положення сидячі), вибухової сили (стрибок у довжину з місця та стрибок з контррухом), а також динамічної рівноваги (стрибок на одній нозі). Сертифіковані фахівці використовували стандартизовані протоколи застосування. Для визначення статистичної значущості було застосовано дисперсійний аналіз із повторними вимірами, а для оцінки розміру ефекту використовувався частковий ета-квадрат (η^2p).

Результати. У результатах як ММТ, так і МФР групи спостерігалось суттєве поліпшення ($p < .05$) за всіма показниками результативності. Група МФР продемонструвала кращі результати порівняно з групою ММТ: гнучкість (+11.58% проти +5.29%, $\eta^2p = .61$), стрибок у довжину з місця (+4.25% проти +2.15%, $\eta^2p = .70$), стрибок з контррухом (+7.68% проти +4.65%, $\eta^2p = .56$) та динамічна рівновага (+4.11% проти +3.03%, $\eta^2p = .29$). Усі зміни були статистично значущими, причому група МФР показала більші розміри ефекту.

Висновки. Дослідження показало, що обидві методики впливу на м'які тканини значно покращили гнучкість, вибухову силу та динамічну рівновагу у елітних футболістів, причому у методиці МФР спостерігалось постійне збільшення відчутних переваг. Отримані результати підкреслюють ефективність впровадження методики МФР у програми передзмагальних розминок для безпосереднього підвищення результативності. Подальші дослідження слід зосередити на вивченні тривалості цих ефектів, показників результативності в конкретних видах спорту та комбінованих протоколів з метою вдосконалення стратегій підготовки до змагань.

Ключові слова: міофасціальне розслаблення, мануальна мобілізація м'яких тканин, спортивна результативність, футболісти, вибухова сила, фасціальна система.

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Acute Effects of Static, Dynamic and Mini-Band Warm-Up Protocols on Some Biomotor Characteristics in Basketball Players

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Abstract

Background. The most effective warm-up programs chosen before training or competition are critically important in terms of performance. This is especially evident in basketball, due to the nature of the game, which requires players to make quick changes of direction and explosive movements. Implementing the most effective warm-up program not only reduces the risk of injury but also ensures that players are fully prepared for the game.

Objectives. This study aimed to determine the acute effects of static warm-up (SWU), dynamic warm-up (DWU) and mini-band warm-up (MBWU) protocols applied to basketball players on speed, jump, strength, flexibility and anaerobic power.

Materials and methods. Ten male basketball players (age: 21.10 ± 1.97 years) from the university basketball team participated in the study voluntarily. The experimental model, one of the quantitative research methods, was used in the study. The study was designed as a three-day program, during which a different warm-up protocol was applied to the same athletes on each day, with 48-hour intervals. After performing SWU, DWU and MBWU protocols, the basketball players underwent a series of assessments, including 10-m sprint, countermovement jump (CMJ), back strength, flexibility and Wingate anaerobic power test (WAnt). The collected data were then recorded. The statistical analysis of the data was conducted using the SPSS package program. The normality level of the data was determined by Shapiro-Wilk test. Repeated Measures ANOVA test was used in the analysis of normally distributed data. The Bonferroni post hoc test was applied for intragroup comparisons.

Results. The findings of this study indicate a significant difference between the warm-up protocols in 10-m sprint, CMJ and peak power (PP) values ($p < 0.05$), while no substantial difference was found in back strength, flexibility, average power (AP) and fatigue index (FI) values ($p > 0.05$).

Conclusions. To sum up, it was determined that the DWU protocol applied to basketball players provided positive developments in speed and CMJ values, while the MBWU protocol led to enhanced improvements in speed, CMJ and PP values. The MBWU protocol demonstrated a beneficial impact on athletic performance compared to the DWU and SWU protocols. It is suggested that the MBWU protocol may be a preferable for warming up in basketball training.

Keywords: anaerobic power, basketball, countermovement jump, sprint, warm-up.

Introduction

Basketball is a popular sport after football today. In this sport, which is played both individually and as a team, gaining an advantage over the opponent requires athletes to adapt to the complex structure of this sport (Kılınç & Özen, 2024). Basketball is related to the fact that individuals

of all age categories can easily practice this sport, as well as athletes having high physical, biomotor and psycho-mental characteristics. In basketball competitions or training, the place of biomotor skills is also very important in addition to some characteristics of athletes (Kılınç, 2008). Basketball is played at a very high tempo, and it includes some biomotor characteristics such as sudden changes of direction, high jumps and sudden acceleration. This situation requires basketball athletes to be athletic, to have basketball skills such as agility, conditioning and explosiveness (Bavlı, 2008).

Warm-up is an important factor in order to maximize performance efficiency in training or competitions. Warm-up increases muscle temperature (Kapnia et al., 2022). It is stated that warmed muscles increase the functionality of the central nervous system and increase the speed of nerve impulses (Karvonen & Lemon, 1992). The muscle-nervous system becomes more efficient due to the increase in temperature, which also increases balance efficiency (Bishop, 2003). It is important for athletes, especially in sports such as basketball, which have high levels of complex body movements, to react quickly to various stimuli.

Sports injuries can occur due to various reasons and at different levels of severity. Individual factors such as muscle strength, performance level, fatigue, warm-up status, and sports technique play a determining role in the occurrence of these injuries (Koç & Yasun, 2024). Especially, an effective warm-up performed before training or competition stands out as an important protective factor in reducing the risk of injury. Warm-up exercises performed before training or competitions are important in terms of athlete performance, as they increase efficiency and cool-down exercises performed afterwards provide advantages in terms of rapid recovery and minimize the risk of injury in both cases (Thacker et al., 2004). SWU exercises are a type of warm-up frequently used before competitions and training. These warm-up exercises increase muscle flexibility at an optimal level, thus improving performance and reducing the risk of possible muscle injuries. DWU exercises are one of the multiple stretching methods that include many movements such as swinging and additional springing in a way that will maintain control without exceeding an athlete's own body weight and joint mobility (Yüksel, 2002). In MBWU exercises, athletes increase their muscle resistance by stretching the band. This increased resistance force in the muscle also increases muscle mass. In addition, MBWU exercises enable athletes to perform movements that cover both single and multiple joints at the same time, allowing for efficient training performance. Resistance enables muscle tension in direct proportion to the stretching of the elastic band, where further increase in muscle tension is related to the thickness and color of the resistance band (Özsu, 2018; Page & Ellenbecker, 2019).

When the studies on warm-up exercises in basketball are examined in the literature, it is seen that warm-up types have a positive effect on performance levels (Meckel et al., 2009; Galazoulas et al., 2012). However, since no study has been found on the effects of SWU, DWU and MBWU exercises on some biomotor characteristics of basketball players, this study was necessary. This study was conducted to determine the acute effects of SWU, DWU and MBWU protocols on some biomotor characteristics. It was assumed that DWU and MBWU protocols would positively affect biomotor characteristics, while SWU protocol would negatively affect them.

Materials and Methods

Study participants

The research group consisted of 10 male basketball players (age: 21.10 ± 1.97 years) from the basketball team of Muş Alparslan University (Turkey). The players participated

in the study voluntarily. The research was conducted in accordance with the Declaration of Helsinki. Before starting the research, Ethics Approval was obtained from the Scientific Research and Publication Ethics Committee of Muş Alparslan University with the decision number 14/51 dated 06.12.2024.

Study Organization

The experimental model, which is a quantitative research method, was used in the study. Athletes who had a chronic disease, had a musculoskeletal injury within the last year and needed to use continuous medication were not included in the study. The participants were shown how to apply the tests in the study, how to use the instruments to be measured and warm-up protocols practically under the supervision of an athletic performance trainer on a day before the study started. The athletes were made to try out the tests to be used in the measurements. The height and body weight measurements of the research group were taken on the same day. All participants were given the necessary instructions to follow regular eating habits on and before the measurement days and not to take any ergogenic supplements and stimulants during the study. They were also advised not to do heavy physical activity for 48 hours before the measurements and not to consume caffeine for 24 hours. The 10 athletes who participated in the study were randomly divided into three groups. Warm-up protocols were applied to the athletes in three groups with an interval of 48 hours, Day 1; Group A (4) SWU, Group B (3) DWU, Group C (3) MBWU, Day 2; Group C (3) SWU, Group A (4) DWU, Group B (3) MBWU, Day 3; Group B (3) SWU, Group C (3) DWU, Group A (4) MBWU (Figure 1). After each warm-up protocol on the measurement days, basketball players were subjected to 10-m sprint, CMJ, back strength, sit and reach flexibility and WAnt tests. Warm-up protocols and tests were performed at the same time (16.00-18.00) on the application days.

Information Day	Rest	Day 1	Rest	Day 2	Rest	Day 3
Providing information about the research and explaining the purpose of the research		Group A (n=4) SWU protocol and tests		Group C (n=3) SWU protocol and tests		Group B (n=3) SWU protocol and tests
Taking anthropometric measurements, introducing the application of warm-up protocols	48 hours	Group B (n=3) DWU protocol and tests	48 hours	Group A (n=4) DWU protocol and tests	48 hours	Group C (n=3) DWU protocol and tests
Introduction of biomotor tests and application of trial tests		Group C (n=3) MBWU protocol and tests		Group B (n=3) MBWU protocol and tests		Group A (n=4) MBWU protocol and tests

Fig. 1. Warm-up protocols and application scheme of tests

Data Collection Tools

10-m sprint test. Athletes' 10-m sprint test was recorded with a photocell device (Fusion Sport Smart Speed, Australia) on a polyurethane coated indoor sports hall floor, with two gates placed at both points with a precision of 0.01 seconds in a 10-m area marked with a start and finish point, and when the athletes felt ready, they ran through the gates at their highest speed from 50 cm behind the start point and two trials were recorded with a 3-min interval. The athletes' best degree was evaluated.

Countermovement jump (CMJ). The athletes' vertical jump skills were measured with a jumping mat (Fusion Sport Smart Jump, Australia), both hands on their waists, feet shoulder-width apart and posture upright, and when the athletes were ready on the mat, they were asked to jump to the highest point they could without taking a step and bending their knees 90°. After jumping, the athletes fell back onto the mat and their jump heights were measured with a precision of 0.1 cm and the two attempts were recorded and the highest degree was evaluated (Atan, 2019).

Back strength. The athletes' back strength was measured with a Takei brand (Japan) back dynamometer. The athletes were placed on the dynamometer stand, stepping on the part where the foot marks were. The athletes were allowed to grip the dynamometer bar with their hands in an inverted position (palms up) while their knees and arms were stretched, their backs were straight and their bodies were slightly bent forward. In this position, the length of the dynamometer chain was adjusted according to the physical characteristics of each athlete and the athletes were asked to pull the dynamometer bar vertically up to the maximum level by taking force from their legs. The test was repeated twice and the best value was recorded in kg.

Sit and reach flexibility test. The test is to extend the body forward as much as possible in a sitting position. The test was performed using a bench with a lower surface length of 35 cm, an upper surface length of 55 cm, a width of 45 and a length of 32 cm. The upper surface of the bench on the subject's side was graded from 0 to 50 cm from the edge and a 30 cm ruler was placed next to this graduation. After the athletes were seated with the soles of their feet on the lower edge of the bench, the distance they could push the ruler on the bench by leaning forward without bending their knees was measured in cm. The athletes were given two attempts and the best degree was recorded (Pense & Serpek, 2010).

Wingate anaerobic power test (WAnT). To determine anaerobic power parameters, WAnT was applied to athletes. The test was performed on a lower extremity bicycle ergometer (Monark 894E, Monark, Varberg, Sweden). WAnT consists of pedaling at maximum speed for 30 s on a bicycle ergometer with a load of 0.075 kp·kg⁻¹ applied for each kilogram of body weight (Ramírez-Vélez et al., 2016). Age, body weight and height of the athletes were recorded on the computer connected to the ergometer via the software of the device. The load to be applied to the athletes was determined by the software and placed on the pan of the ergometer. The saddle height of the ergometer was adjusted according to the height of the athletes. The feet of the athletes were fixed to the pedals with the help of clips. After a 5-min free warm-up period, the athletes performed a 3-min pedaling exercise without exceeding 50-60 rpm without load on the ergometer. After the determined load was placed on the bicycle pan, the athlete started the test when he/she felt ready. After reaching the maximum pedal speed, the load on the pan was automatically reduced and the resistance caused by the weight was reflected to the pedal. After this stage, the participants were asked to complete the test with maximum effort by maintaining the pedal speed for 30 seconds. The athletes were motivated verbally while applying WAnT. After completing WAnT, the PP and MP anaerobic power parameters were determined by the software of the ergometer. It was calculated from the formula Fatigue Index = (Peak Power-Minimum Power) / (Peak Power) × 100 (Zagatto et al., 2009).

Warm-up Protocols

Static warm-up protocol. The static warm-up protocol consists of two parts. The first part consists of 5 min of low-tempo running, and the second part consists of 15 different movements for the upper and lower extremities and other parts of the body. The exercises were continued for 15 sec and then a 10 sec rest was given. Static warm-up exercises were applied as 1 set in a 20 x 20-m area according to the order of movements under the supervision of an athletic performance trainer (Table 1). The static warm-up protocol lasted a total of 15 min, consisting of 5 min of running and 10 min of warm-up exercises.

Table 1. Static warm-up protocol

Static Warm-Up Exercises	Set	Exercise Direction	Exercise Time (sec)	Rest Time (sec)
Overhead Arm Stretch	1	Single	15	10
Overhead Triceps Stretch	1	Double	30	20
Cross Body Shoulder Stretch	1	Double	30	20
Chest Stretch	1	Double	30	20
Rear Shoulder Stretch	1	Single	15	10
Side Stretch	1	Double	30	20
Crouch Leg Stretch	1	Double	30	20
Quadriceps Stretch	1	Double	30	20
Floor Touch	1	Single	15	10
Calf Stretch	1	Double	30	20
Butterfly Stretch	1	Single	15	10
Head to Knee Stretch	1	Double	30	20
Hamstring Stretch	1	Double	30	20
Double Knee to Chest Stretch	1	Single	15	10
Abdomen Stretch	1	Single	15	10
Total			600 sec	

Dynamic warm-up protocol. The dynamic warm-up protocol consists of two parts. The first part consists of 5 min of low-tempo running, and the second part consists of 11 different movements for the upper and lower extremities and other parts of the body. The exercises were continued for 15 sec and then a 10 sec rest was given. Dynamic warm-up exercises were

Table 2. Dynamic warm-up protocol

Dynamic Warm-Up Exercises	Set	Exercise Direction	Exercise Time (sec)	Rest Time (sec)
Shoulder Circles	2	Single	15	10
Arm Swings	2	Single	15	10
Hip Circles	2	Single	15	10
Jumping Jacks	2	Single	15	10
Leg Swings	2	Double	30	20
Walking High Kicks	2	Single	15	10
Squats	2	Single	15	10
High Knees	2	Single	15	10
Butt Kicks	2	Single	15	10
Walking Lunge	2	Single	15	10
Ankle Hops	2	Single	15	10
Total			2 × 300 = 600 sec	

applied in 2 sets in a 20 × 20-m area, according to the order of movements, under the supervision of an athletic performance trainer (Table 2). The dynamic warm-up protocol lasted a total of 15 min, 5 min of running and 10 min of warm-up exercises.

Mini band warm-up protocol. The mini band warm-up protocol consists of two parts. The first part consists of 5 min of low-tempo running, and the second part consists of 10 different movements for the upper and lower extremities and other parts of the body. The exercises were continued for 15 sec and then a 10 sec rest was given. The mini band warm-up exercises were applied in 2 sets in a 20 × 20-m area, according to the order of movements, under the supervision of an athletic performance trainer (Table 3). The mini band warm-up protocol lasted a total of 15 min, consisting of 5 min of running and 10 min of warm-up exercises.

Table 3. Mini band warm-up protocol

Mini Band Warm-Up Exercises	Set	Exercise Direction	Exercise Time (sec)	Rest Time (sec)
Overhead Pulses	2	Single	15	10
Arm Pulses	2	Single	15	10
Lat Pulldown	2	Single	15	10
Jumping Jacks	2	Single	15	10
Lateral Walk	2	Single	15	10
Squats	2	Single	15	10
Bicycle Crunch	2	Single	15	10
Hamstring Curl	2	Double	30	20
Clamshell	2	Double	30	20
Butterfly Bridge	2	Single	15	10
Total		2 × 300 = 600 sec		

Statistical Analysis

SPSS package program was used for processing the data obtained from the research, descriptive statistics and

statistical analysis of the data. The normality assumption of the data was tested with the Shapiro-Wilk test. Repeated Measures ANOVA from parametric tests and Bonferroni test from Post Hoc tests were applied to the data showing normal distribution. The significance level in the research was accepted as $p < 0.05$.

Results

Descriptive statistics of the general characteristics of the basketball players participating in the study are presented in Table 4. The results of the biomotor tests of the basketball players belonging to the SWU, DWU and MBWU protocols are presented in Table 5 and Figure 2.

Table 4. Descriptive statistics of the general characteristics of the participants

General characteristics	n	Mean	SD
Age (years)	10	21.10	1.97
Height (cm)	10	184.00	7.44
Body Weight (kg)	10	81.74	12.59
BMI (kg/m ²)	10	24.05	2.58

According to the findings in Table 5, a significant difference was found between the warm-up protocols in 10-m sprint, CMJ and PP tests ($p < 0.05$). No significant difference was found between the warm-up protocols in back strength, flexibility, MP and FI values ($p > 0.05$).

In the 10-m sprint test of basketball players, it was determined that the DWU and MBWU protocols had lower values than the SWU protocol. In the CMJ test, it was found that the DWU protocol had higher values than the SWU protocol, while the MBWU protocol had higher values than the SWU and DWU protocols. In the PP value, it was determined that the MBWU protocol had higher values than the SWU protocol.

Table 5. Biomotor test results of warm-up protocols

Biomotor tests	Warm-up protocols (n=10)			F	p	Post Hoc
	Static ¹ Mean ± SD	Dynamic ² Mean ± SD	Mini Band ³ Mean ± SD			
10-m Sprint (sec)	1.80 ± 0.09	1.74 ± 0.08	1.70 ± 0.11	5.277	0.016	2<1 - 3<1
CMJ (cm)	35.35 ± 6.25	37.93 ± 6.11	39.65 ± 5.77	37.307	0.000	2>1 - 3>1,2
Back Strength (kg)	142.95 ± 18.01	145.20 ± 23.01	152.25 ± 14.43	2.569	0.104	p>0.05
Flexibility (cm)	33.15 ± 6.09	33.10 ± 5.78	35.60 ± 6.37	3.244	0.098	p>0.05
Peak Power (W/kg)	10.87 ± 1.44	11.44 ± 1.15	11.87 ± 1.20	6.233	0.009	3>1
Mean Power (W/kg)	7.78 ± 0.60	7.93 ± 0.62	7.96 ± 0.41	1.151	0.339	p>0.05
Fatigue Index (%)	58.90 ± 7.15	59.73 ± 3.20	65.25 ± 9.39	2.854	0.084	p>0.05

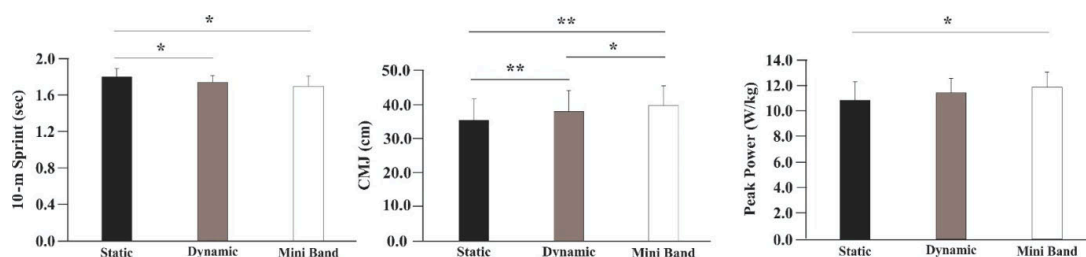


Fig. 2. Values of 10-m sprint, CMJ and peak power tests

Discussion

One of the important findings of this study is that warm-up has an effect on biomotor characteristics. Especially DWU and MBWU provided an increase in athletic performance as assumed. There are studies showing that SWU protocols neither improve nor decrease athletic performance or are not beneficial (Galazoulas, 2017; Aydoğdu & Atlı, 2021; Needham et al., 2009; Yamaguchi & Ishii, 2005). In the present study, a significant difference was determined between the warm-up protocols in the 10-m sprint test of basketball players. It was found that DWU and MBWU protocols had lower values than SWU protocol in the 10m sprint test. In a study applied to basketball players, it was determined that DWU protocol provided more positive results compared to SWU protocol in the 10m sprint test (Galazoulas, 2017). MBWU exercises after activation in university athletes showed statistically significant improvements in speed test (Singh et al., 2023). It was found that the values obtained after DWU in the speed test of young basketball players were statistically lower than the values obtained after SWU (Aydoğdu & Atlı, 2021). In a study conducted on young basketball players, it was observed that DWU exercises performed before the 20-m sprint test had a positive effect on the 20m sprint (Akyüz et al., 2017). In the 20-m sprint test, the FIFA 11+ warm-up protocol values of young futsal players were found to be lower than the DWU and SWU protocols, and the DWU protocol values were also found to be lower than the SWU protocol (Kahraman et al., 2023). It can be said that the results in our study are similar to the studies in the literature. However, there are also studies in the literature with different results. In another study conducted on university women's football team athletes, there was no significant difference between the SWU and MBWU protocols in the 10m sprint test (Christensen et al., 2020). The difference between the results in our study and the results in this study is due to the differences in the branch and warm-up protocols.

In the current study, a significant difference was determined between the warm-up protocols in the CMJ test of basketball players. While the DWU protocol was found to have higher values than the SWU protocol in the CMJ test, the MBWU protocol was found to have higher values than the SWU and DWU protocols. A study conducted on young male basketball players showed that the FIFA 11+ warm-up protocol was more beneficial than the DWU protocol in the vertical jump test (Işıkdemir et al., 2020). A different study applied to basketball players determined that the DWU protocol provided more positive results compared to the SWU protocol in the CMJ test (Galazoulas, 2017). Another study found that the DWU protocol applied to athletes with and without weight vests increased vertical jump performance more than the SWU protocol (Faigenbaum et al., 2006). It was determined that DWU exercises increased drop jump performance and that a 10-min dynamic exercise period affected drop jump performance more positively than 5-min and 15-min warm-up periods (Kızılcı & Okut, 2024). It was determined that the vertical jump values after DWU in young basketball players were statistically higher than the values obtained after SWU (Aydoğdu & Atlı, 2021). It can be said that the results of our study are similar to the studies in the literature. However, there are also studies in the literature with different results. There was no significant difference between the

SWU and MBWU protocols in the vertical jump test in female football players (Christensen et al., 2020). It has been determined that static warm-up exercises have a positive effect on CMJ performance in basketball players (Sarıkaya et al., 2023). The difference between the results in our study and the results in this study is due to the difference in warm-up protocols.

In the current study, no significant difference was found between the warm-up protocols in the back strength and flexibility tests of basketball players. In a study conducted on young basketball players and supporting the results in our study, it was determined that SWU and DWU protocols had no effect on back and leg strength (Akyüz et al., 2017). However, there are also studies in the literature with different results. After dynamic stretching exercise, the latency of isometric contraction in the elbow flexor muscles was reduced and an increase in strength was determined after 10 min of rest (Veevo et al., 2012). It was determined that there was a statistically significant difference in the flexibility values of chronically applied static and dynamic warm-up exercises in adolescent basketball players (Esmer & Eskiyecek, 2020). It was found that SWU exercises applied before the sit-and-reach flexibility test in young basketball players had a positive effect on flexibility (Akyüz et al., 2017). It has been determined that the flexibility values obtained after DWU in basketball players are statistically higher than the values obtained after SWU (Aydoğdu & Atlı, 2021). The difference between the results in our study and the results in the literature is due to the number of exercises in the warm-up protocols, the preference of different exercises and the difference in the application time.

In the present study, a significant difference was determined between the warm-up protocols in the PP anaerobic parameter of basketball players. It was determined that the MBWU protocol had higher values than the SWU protocol in the PP value. No significant difference was found in the FI and PP anaerobic parameters between the general warm-up and SWU protocols without warm-up (Amani et al., 2016). It was determined that different warm-up times did not create a significant difference in the PP and MP anaerobic parameters in handball players (Harmanlı et al., 2014). In a study conducted on basketball, handball and volleyball players, it was found that there was no significant difference in the peak torque muscle strength values between the active, passive and combined warm-up groups during extension and flexion applied slowly and quickly (Ahsan & Mohammad, 2018). The difference between the results in our study and the results in these studies is due to the differences in the branches and warm-up protocols. There are also studies in the literature supporting the results of the study. After activation, MBWU exercises did not provide an improvement in muscle strength peak torque at high speeds (120°/s) but showed improvements at low speeds (60°/s) (Singh et al., 2023). It has been determined that a high-intensity specific warm-up protocol has higher values in 1-maximum repetition squat performance in basketball players than a low-intensity specific warm-up and a low-intensity 5-min running protocol alone (Eken, 2021).

Conclusions

According to the results obtained from the research, a significant difference was found between the warm-up protocols applied to basketball players in the 10-m sprint, CMJ

and PP tests. No significant difference was found between the warm-up protocols in back strength, flexibility, MP and FI values. It was determined that the DWU and MBWU protocols had lower values than the SWU protocol in the 10-m sprint test of basketball players. While the DWU protocol was found to have higher values than the SWU protocol in the CMJ test, it was found that the MBWU protocol had higher values than the SWU and DWU protocols. It was determined that the MBWU protocol had higher values than the SWU protocol in the PP value. As a result, the MBWU protocol applied to basketball players provided more improvement in athletic performance compared to the DWU and SWU protocols. It is suggested that the MBWU protocol may be a preferable warm-up protocol in basketball training.

Conflict of Interest

The authors declare that they have no conflicts interests.

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Ефективний вплив застосування протоколів статичної, динамічної розминок та розминки із використанням міні-стрічок на певні біомоторні характеристики баскетболістів

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

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Історія питання. Вибір найефективніших програм розминки перед тренуванням або змаганням має вирішальне значення з точки зору результативності. Особливо яскраво це простежується в баскетболі, оскільки характер цієї гри вимагає від гравців швидкої зміни напрямку руху та виконання вибухових рухів. Впровадження найбільш ефективної програми розминки не тільки знижує ризик травмування, але й забезпечує комплексну підготовку гравців до гри.

Мета дослідження. Мета цього дослідження полягала у визначенні ефективного впливу застосування протоколів статичної розминки (СР), динамічної розминки (ДР) та розминки із використанням міні-стрічок (МСР) для баскетболістів на показники швидкості, стрибка, сили, гнучкості та анаеробної потужності.

Матеріали та методи. У дослідженні добровільно взяли участь десять баскетболістів-чоловіків (вік: 21,10 ± 1,97 роки) з університетської баскетбольної команди. У дослідженні використовувалася експериментальна модель, що є одним із

кількісних дослідницьких методів. Дослідження було розроблено за триденною програмою, під час якої щодня, з інтервалом у 48 годин, до тих самих спортсменів застосовувався різний протокол розминки. Після виконання протоколів СР, ДР та МСР баскетболісти пройшли низку тестів, що включала спринт на 10 метрів, стрибок із контррухом (КРС), оцінювання показників сили м'язів спини, гнучкості та тест Вінгейта на визначення анаеробної потужності (ВАНт). Наступний етап передбачав фіксування зібраних даних. Статистичний аналіз даних проводився із використанням програмного забезпечення SPSS. Рівень нормальності даних визначався за допомогою критерію Шапіро-Вілка. З метою аналізу нормально розподілених даних використовувався дисперсійний аналіз із повторними вимірами. Для внутрішньогрупових порівнянь застосовувався post-hoc тест Бонферроні.

Результати. Результати цього дослідження вказують на значну різницю між протоколами розминок у показниках спринту на 10 метрів, КРС та пікової потужності (ПП) ($p < 0.05$), тоді як суттєвої різниці у показниках сили м'язів спини, гнучкості, середньої потужності (СП) та індексу втоми (ІВ) не встановлено ($p > 0.05$).

Висновки. Підсумовуючи, було визначено, що застосування протоколу ДР для баскетболістів, забезпечило позитивні зміни в показниках швидкості та КРС, тоді як протокол МСР призвів до значного поліпшення показників швидкості, КРС та ПП. Протокол МСР продемонстрував сприятливий вплив на спортивну результативність, порівнюючи з протоколами ДР та СР. Висловлюється припущення, що протокол МСР можна вважати оптимальним варіантом для розминки під час тренувань з баскетболу.

Ключові слова: анаеробна потужність, баскетбол, стрибок із контррухом, спринт, розминка.

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Original Scientific Article

Cognitive-Reflective Motor Learning – Based Physical Education to Enhance Critical Thinking Abilities: Does RASCH Analysis Model show the Significant Evidence?

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Abstract

Background. This study addresses the need to enhance cognitive-reflective competencies in physical education, which often prioritizes mastering basic sports skills at the expense of cognitive development. In the information era, critical thinking is a crucial cognitive-reflective skill that must be fostered.

Objectives. The study aimed to examine the structural design of instructional didactics and to assess changes in the difficulty levels of critical thinking among students in physical education settings.

Materials and methods. A posttest-only control group design was employed, with critical thinking data collected after the physical education sessions. The study involved two groups: an experimental class that integrated cognitive learning through tennis and a control class that participated in futsal extracurricular activities, each comprising 30 junior high school students (aged 13-14 years).

Results. Results analyzed using RASCH modelling revealed significant shifts in critical thinking difficulty levels. Specifically, indicators of critical thinking, including inference, assumption recognition, deductive reasoning, interpretation, and argument assessment, showed a 70% reduction in difficulty for students in the experimental group compared to those in the control group.

Conclusions. These findings suggest that cognitive-reflective learning in physical education can significantly enhance students' critical thinking abilities, with students in the experimental class demonstrating higher critical thinking skills than their counterparts in the control group.

Keywords: physical education, cognitive-reflective learning, critical thinking, RASCH model, junior high school.

Introduction

Physical education is widely recognized as an educational process that utilizes physical activity as a medium to cultivate various dimensions of human potential (Vaughan et al., 2019). The instructional process in physical education is deliberately structured to facilitate meaningful learning experiences, thereby promoting students' physical, emotional, social, and intellectual development (Boelens et al., 2017; Nur et al. 2023). To achieve these outcomes, physical education must transcend its traditional focus on physical skills and serve as a conduit for holistic student development. Effective programs should engage the full range of student competencies—cognitive, psychomotor, and affective (Robinson et al., 2018). However, a critical yet often neglected pedagogical objective is the cultivation of

students' cognitive-reflective abilities. While the discipline continues to emphasize immediate outcomes such as physical fitness, skill acquisition, and sportsmanship (Kelly, 2019), cognitive-reflective competencies—especially those that encourage students to reflect on their learning processes and outcomes—are frequently underdeveloped.

This concern is further supported by evidence indicating that quality physical education should integrate not only socio-motor and techno-motor development but also the cognitive-reflective domain (Lorente Sanz et al., 2023; Van Deventer, 2014). Cognitive-reflective competence, particularly in relation to metacognitive awareness and critical evaluation, plays a crucial role in improving students' capacity for lifelong learning and decision-making. Neurocognitive research suggests that physical activity can enhance synaptic plasticity in the cerebral cortex, a region associated with higher-order thinking and executive function, thus reinforcing the link between movement and cognitive development (Donnelly et al., 2013).

Despite these insights, prior research underscores a persistent gap in physical education pedagogy, notably the limited emphasis on cognitive engagement and student attitudes (Norris et al., 2020). The dominance of teacher-centered instruction and an overemphasis on the mastery of technical sport skills have constrained opportunities for students to engage in deeper cognitive processing (Burhaein et al., 2020). Within the reflective cognitive domain, the development of critical thinking is especially imperative in today's complex, information-rich world. Critical thinking is defined as the application of cognitive strategies that enhance the probability of achieving desired outcomes through purposeful, reasoned, and goal-directed thought (Lai, 2011). It encompasses skills such as problem-solving, inference, and evaluative reasoning, and involves the capacity to provide justifiable decisions based on reflective judgment (Ennis, 2015; Halpern, 1998). Researchers further assert that critical thinking requires the ability to connect abstract concepts, understand complex information, and apply knowledge effectively across contexts (Beyer, 1988; Elder & Paul, 2020; Solso et al., 2005).

In physical education, critical thinking manifests in the ability to analyze and solve movement-based problems, devise strategic responses, and coordinate sequences of bodily movements in context-specific scenarios (Pill & SueSee, 2017; Tishman & Perkins, 1995). Teaching strategies that integrate movement problems challenge students to analyze, evaluate, and synthesize information, thereby promoting critical reflection and decision-making (Bidzan-Bluma & Lipowska, 2018). The integration of critical thinking into physical education aligns with broader educational mandates that aim to foster students' intellectual capabilities as part of national development agendas (National Research Council, 2012). Consequently, there is an urgent need to reconceptualize physical education not only as a platform for physical skill acquisition but also as a space for cognitive development.

Despite growing recognition of the cognitive potential of physical education, research in this domain—particularly in the national context—remains limited. Addressing this gap, the present study investigates how physical education teachers can purposefully design instructional strategies to cultivate students' critical thinking skills. Specifically, this research examines changes in the difficulty levels of students' critical thinking using a cognitive-reflective instructional model in tennis classes, compared to traditional futsal extracurricular activities, through the lens of the RASCH measurement model.

The novelty of this research lies in its application of the RASCH model—typically used in affective assessments—to evaluate critical thinking within physical education settings. While previous studies have predominantly focused on emotional and behavioral outcomes (Muslihin et al., 2022; Nur et al., 2020; Nur et al., 2022; Nur et al., 2025), this study provides empirical insights into the cognitive dimension of motor learning. Furthermore, the integration of cognitive-reflective strategies in different physical education contexts (tennis vs. futsal) offers innovative pedagogical alternatives for enhancing students' critical thinking abilities. The aim of this research is to provide empirical evidence on the effectiveness of cognitive-reflective motor learning approaches in fostering critical thinking in physical education, thereby broadening the pedagogical scope and assessment practices within the discipline.

Materials and Methods

Study Participants

The study involved 60 junior high school students aged 13–14 years, who were randomly assigned into two groups: an experimental group ($n = 30$) and a control group ($n = 30$). Participants were selected from the same school to maintain environmental consistency and to ensure comparable levels of physical and cognitive development across both groups. Informed consent was obtained from both students and their guardians prior to participation.

Study Organization

This experimental study employed a posttest-only control group design, adapted from Ennis (1987). The aim was to evaluate the relative impact of a cognitive-based physical education intervention on students' critical thinking skills. The research design is illustrated in Figure 1.

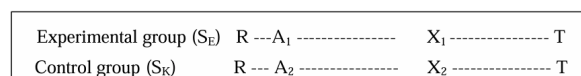


Fig. 1. Research Design (Posttest-Only Control Group Design). Information: R: Random assignment. A_1 : Experimental group. A_2 : Control group. X_1 : Treatment involving cognitive-reflective instruction using tennis. X_2 : Conventional extracurricular futsal activity. T: Posttest measurement of critical thinking skills

The experimental group (S_E) received instructional treatment that integrated cognitive-reflective learning through tennis games. The intervention focused on aligning physical movement with cognitive processes using a movement/game problem-situated learning approach. The control group (S_K) participated in regular futsal extracurricular activities without targeted cognitive integration. The treatment was implemented through a structured didactic sequence over eight sessions, each designed to develop specific critical thinking components. The instructional stages included: 1) getting students' attention and attention; 2) facilitating students to actively move to learn and actively learn to move in the relationship of critical thinking abilities; 3) facilitating students to think critically through the presentation of movement/games problem situated learning; 4) developing games/movement problem situated learning with elements of critical thinking abilities; 5) making the relevance of critical thinking abilities in movement and play situations with critical thinking abilities in everyday life. These stages are methodically carried out in sequence, as in Figure 2.

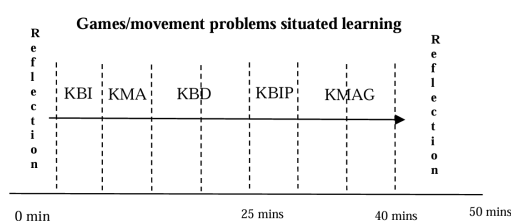


Fig. 2. Methodical treatment in the games/movement problem situated learning stage

The effectiveness of movement-based learning is reinforced through game and movement-situated activities. Students' critical thinking skills are developed by presenting progressively challenging movement tasks and game scenarios. The instructional treatment was administered over eight sessions, each designed to align with the components of critical thinking within these movement or game-based learning contexts. By associating movement tasks and games with critical thinking elements, students were encouraged to engage in deeper, reflective thinking. Figure 3 illustrates the repetition and structure of this treatment across the eight sessions.

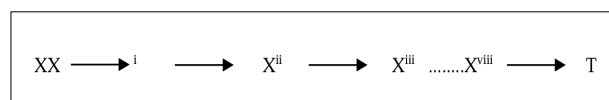


Fig. 3. Series of 8-meeting treatments

To assess critical thinking ability, a 40-item questionnaire was developed based on Ennis's (1987) critical thinking framework. Items were distributed across five key indicators, each comprising eight items on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). This instrument was developed by following the grid as shown in table 1. The instrument underwent expert review and field validation. Validity testing showed that all items were statistically valid, with t-count values exceeding the t-table value of 2.14. Reliability analysis yielded a Cronbach's Alpha of 0.885, indicating a high internal consistency of 88.5%.

Table 1. Critical Thinking Instrument Grid

No	Indicator	Total Item	Item Number
1	Inferential Thinking Ability (IBT) Seeking relevance Determining the evidence Drawing conclusions Expanding alternatives	8	1-8
2	Ability to Recognize Assumptions (KMA) Recognizing logical basis Doing categories Emphasizing the meaning Testing ideas	8	9-16
3	Deductive Thinking Ability (DBT) Looking for evidence Stating the conclusion Justifying procedures Presenting arguments	8	17-24
4	Interpretive Thinking Skills (KBIP) Categorizing Marking significance Emphasizing the meaning Positioning one's own opinion	8	25-32
5	Ability to Evaluate Arguments (KMAG) Recognizing arguments Analyzing arguments Assessing arguments Expressing an opinion	8	33-40

Statistical Analysis

Quantitative data were analyzed using a two-stage statistical approach. First, SPSS version 24 was employed to evaluate the validity and reliability of the critical thinking instrument. Second, the posttest data from both groups were analyzed using RASCH modeling via Winsteps software version 5.3.2.0. This psychometric method allowed for a detailed evaluation of item difficulty and student ability across indicators of critical thinking. RASCH analysis was particularly instrumental in identifying shifts in task difficulty levels between the experimental and control groups, offering nuanced insights into the impact of the cognitive-reflective intervention.

Results

RASCH analysis will determine the extent to which diversity is measured by an instrument so that it can be known whether the instrument can measure what should be measured (Ary et al. 2018). Data on the pattern of changes in the level of difficulty of critical thinking items is obtained through the items filled in by respondents. Items in the control class are marked with the letter code (A), and (B) is the code for items in the experimental class. In the results of this data, researchers will reveal and analyze the differences in the level of difficulty of critical thinking items in the control class and the experimental class by paying attention to the standard deviation value (0.22) and the logit value in the measure column for each item. The level of difficulty of the items is classified into four categories, namely: (1) very difficult group, namely $> +1$ SD (0.22); (2) difficult group for 0.0 logit to $+1$ SD (0.22); (3) easy group for 0.0 logit to -1 SD (1, 10); and (4) very easy group is < -1 SD (0.22) (Andrich, 2010; Sumintono, 2018). The following table shows the level of difficulty of critical thinking items in the control class and experimental class.

Next, a table will be presented showing the percentage of the level of difficulty of critical thinking items in the control class and the experimental class.

Table 3 shows that as many as 67.5% of critical thinking items can be categorized as very difficult and difficult and 32.5% of critical thinking items can be categorized as easy and very easy for students in the control class, which can be interpreted those students in the control class experience cognitive problems in developing critical thinking skills. While the cognitive conditions of students in the experimental class show that only 35% of critical thinking items can be categorized as very difficult and difficult and 65% of critical thinking items can be categorized as easy and very easy, which means that students' cognitive abilities are quite high in developing critical thinking skills.

Furthermore, the pattern of changes in the magnitude of the level of difficulty of critical thinking items in the control and experimental classes that show significant changes can be seen through the difference in values (logit differences) in the control and experimental classes or using racking analysis through RASCH modeling (Laliyo et al. 2022).

Table 4 shows the differences in the difficulty levels of the items, some are negative, and some are positive. In critical thinking item number 1, it is shown that the item in the control class has a positive value (+) while in the

Table 2. Comparison of the Level of Difficulty of Critical Thinking Instrument Items in the Control and Experimental Classes

Items in Control Class			Items in Experimental Class		
Items	Measure	Item Category	Items	Measure	Item Category
A01	0.06	Difficult	B01	-0.11	Easy
A02	0.11	Difficult	B02	0.15	Difficult
A03	0.00	Difficult	B03	0.06	Difficult
A04	0.3	Very difficult	B04	0.25	Very difficult
A05	0.25	Very difficult	B05	0.22	Difficult
A06	-0.16	Easy	B06	-0.34	Very easy
A07	-0.36	Very easy	B07	-0.08	Easy
A08	-0.18	Easy	B08	-0.01	Easy
A09	-0.21	Easy	B09	-0.38	Very easy
A10	0.00	Difficult	B10	-0.29	Very easy
A11	0.15	Difficult	B11	0.41	Very difficult
A12	0.02	Difficult	B12	0.05	Difficult
A13	-0.46	Very easy	B13	-0.76	Very easy
A14	0.33	Very difficult	B14	0.08	Difficult
A15	-0.01	Easy	B15	-0.03	Easy
A16	-0.72	Very easy	B16	-0.55	Very easy
A17	-0.36	Very easy	B17	-0.21	Difficult
A18	0.28	Very difficult	B18	0.22	Difficult
A19	0.18	Difficult	B19	0.11	Difficult
A20	0.06	Difficult	B20	-0.14	Easy
A21	0.02	Difficult	B21	-0.15	Easy
A22	-0.14	Easy	B22	-0.19	Easy
A23	-0.15	Easy	B23	-0.31	Very easy
A24	0.11	Difficult	B24	-0.12	Easy
A25	0.13	Difficult	B25	0.38	Very difficult
A26	-0.11	Easy	B26	-0.08	Easy
A27	0.22	Difficult	B27	0.06	Difficult
A28	0.22	Difficult	B28	-0.18	Easy
A29	-0.01	Easy	B29	-0.27	Very easy
A30	0.04	Difficult	B30	0.05	Difficult
A31	-0.05	Easy	B31	-0.07	Easy
A32	0.02	Difficult	B32	-0.01	Easy
A33	0.21	Difficult	B33	-0.09	Easy
A34	0.18	Difficult	B34	-0.05	Easy
A35	0.24	Very difficult	B35	-0.14	Easy
A36	0.23	Very difficult	B36	-0.05	Easy
A37	0.14	Difficult	B37	0.20	Difficult
A38	0.17	Difficult	B38	-0.07	Easy
A39	0.14	Difficult	B39	-0.14	Easy
A40	0.25	Very difficult	B40	-0.02	Easy

Table 3. Percentage of Critical Thinking Instrument Item Difficulty in Control and Experimental Classes

Control Class			Experimental Class		
Category	Total	Percentage	Category	Total	Percentage
Very difficult	7	17.5 %	Very difficult	3	7.5 %
Difficult	20	50 %	Difficult	11	27.5 %
Easy	9	22.5 %	Easy	19	47.5 %
Very easy	4	10 %	Very easy	7	17.5 %

Table 4. Critical Thinking Ability Instrument Racking Analysis

Item	Class Control	Class Experimental	Logit Difference
1	0.06	-0.11	0.17
2	0.11	0.15	-0.04
3	0.00	0.06	-0.06
4	0.3	0.25	0.05
5	0.25	0.22	0.03
6	-0.16	-0.34	0.18
7	-0.36	-0.08	-0.28
8	-0.18	-0.01	-0.17
9	-0.21	-0.38	0.17
10	0.00	-0.29	0.29
11	0.15	0.41	-0.26
12	0.02	0.05	-0.03
13	-0.46	-0.76	0.3
14	0.33	0.08	0.25
15	-0.01	-0.03	0.02
16	-0.72	-0.55	-0.17
17	-0.36	-0.21	-0.15
18	0.28	0.22	0.06
19	0.18	0.11	0.07
20	0.06	-0.14	0.2
21	0.02	-0.15	0.17
22	-0.14	-0.19	0.05
23	-0.15	-0.31	0.16
24	0.11	-0.12	0.23
25	0.13	0.38	-0.25
26	-0.11	-0.08	-0.03
27	0.22	0.06	0.16
28	0.22	-0.18	0.4
29	-0.01	-0.27	0.26
30	0.04	0.05	-0.01
31	-0.05	-0.07	0.02
32	0.02	-0.01	0.03
33	0.21	-0.09	0.3
34	0.18	-0.05	0.23
35	0.24	-0.14	0.38
36	0.23	-0.05	0.28
37	0.14	0.20	-0.06
38	0.17	-0.07	0.24
39	0.14	-0.14	0.28
40	0.25	-0.02	0.27

experimental class it has a negative value (-), meaning that the item has a difference where in the control class the item means difficult, while in the experimental class the item means easy. As for the logit difference, it will show the level of significance of the difference in the logit of the critical thinking item in the control and experimental classes. For the logit value, it is stated to have a high level of significance if the logit difference value is > 0.05 , a positive value in the logit difference means that there is an increase in the item difference while a negative value in the logit difference means that there is a decrease in the item difference. In this case, item number 1 has a logit value of 0.17 which means that item 1 experiences an increase in student cognitive,

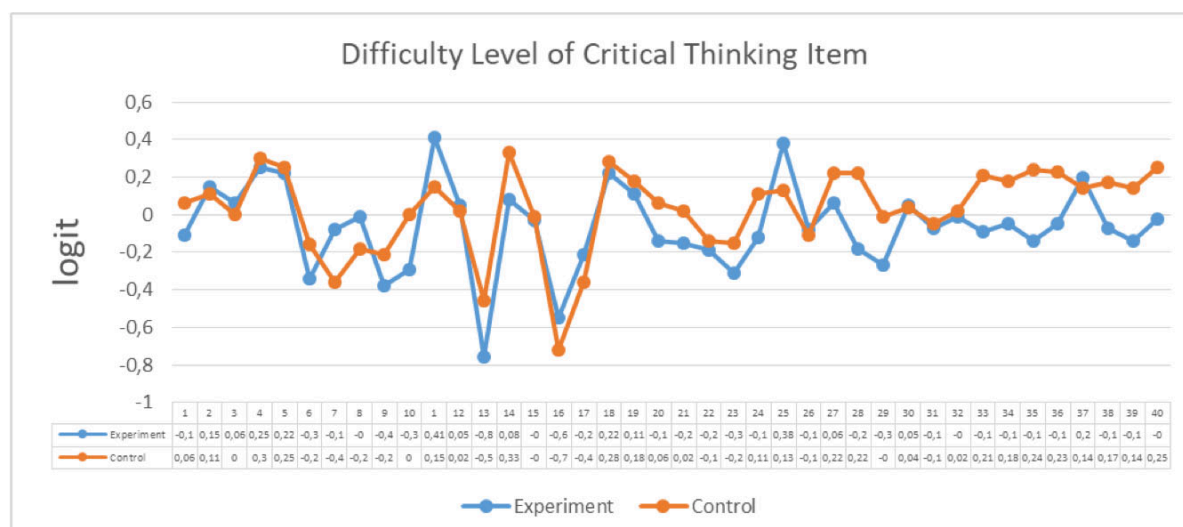


Fig. 4. Level of Difficulty in Critical Thinking Items

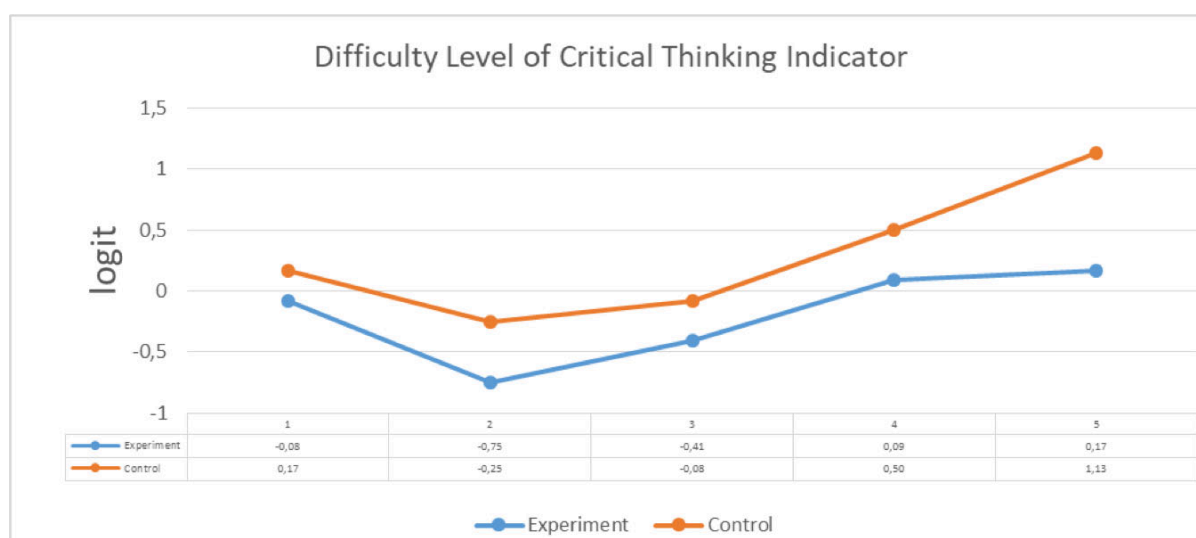


Fig. 5. Level of Difficulty in Critical Thinking Items

where students' critical thinking skills (item number 1) are better in the experimental class than in the control class. Based on the logit difference in critical thinking items, there are 28 items with positive values, which means that there is cognitive mastery in the experimental class in developing critical thinking skills by 70%. Furthermore, information regarding the differences in logit or the level of difficulty of critical thinking items is presented in the graph.

The graph in Figure 4 illustrates the changes in item difficulty levels. Significant decreases in difficulty (indicating easier items) were observed in items 1, 4, 6, 9, 10, 13, 14, 18, 19, 20, 21, 22, 23, 24, 27, 28, 29, 33, 34, 35, 36, 37, 38, and 39, accounting for 28 items (60%). Items with an insignificant decrease in difficulty included 5, 15, 31, and 32, representing 4 items (10%). Conversely, significant increases in item difficulty (indicating more complex tasks) were noted in items 3, 7, 8, 11, 16, 17, 25, and 37, totaling 8 items (20%). Items 30, 26, 12, and 2 showed an insignificant increase in difficulty, covering 4 items (10%). These findings suggest that while students demonstrated progress in cognitive processes

related to critical thinking development, there is still a need for further cognitive teaching support to enhance these skills. A detailed analysis of each critical thinking indicator is depicted in the graph.

The graphic results in Figure 5 indicate that for each critical thinking indicator—namely, inference ability, the ability to recognize assumptions, deductive reasoning, interpretation skills, and the ability to assess arguments—there was a notable decrease in difficulty levels. Specifically, 70% of the critical thinking items completed by students in the control class exhibited a lower difficulty level when compared to those completed by students in the experimental class. This suggests that students in the experimental class developed higher critical thinking skills than those in the control group.

Discussion

Based on the main hypothesis in this study, it is assumed that there is a significant difference in the level of difficulty of the critical thinking instrument items between the control and

experimental classes as a result of the application of different learning strategies. RASCH analysis was used to evaluate the validity and accuracy of the instrument in measuring critical thinking skills as well as identifying changes in the pattern of item difficulty levels in each group. The results showed that the distribution of item difficulty levels in the control class was dominated by the “difficult” and “very difficult” categories (67.5%), while the experimental class showed dominance in the “easy” and “very easy” categories (65%). This finding shows that the learning strategy applied in the experimental class has a positive impact on the development of students’ critical thinking skills, which is in line with the results of previous research which states that innovative learning approaches can improve students’ higher-order thinking skills (Sumintono, 2018; Laliyo et al., 2022).

Comparison of data between control and experimental classes shows significant logit differences in most items, especially in 28 out of 40 items that show positive logit values with a difference of more than 0.05, indicating an increase in cognitive mastery in the experimental class. For example, on item number 1, there is a logit difference of 0.17, indicating that students in the experimental class were able to solve the problem more easily than students in the control class. This finding strengthens the argument that pedagogical interventions designed with a structured approach and based on critical thinking competencies are able to direct students in building more adaptive cognitive strategies (Ary et al., 2018; Andrich, 2010).

The process of cultivating critical thinking through movement tasks, such as tennis instruction, focuses primarily on providing reasons and evaluations of movement task performance. This involves the ability to explain what and how a movement task is executed, helping to sharpen the mind’s ability to process these tasks. Key skills developed include decision-making regarding movements, predicting ball trajectories, evaluating shot outcomes, synthesizing movement sequences, understanding shot positioning, classifying shot types, and comparing different playing styles. These cognitive processes during movement tasks demonstrate the positive role of physical activity in enhancing critical thinking skills (Huang & Ning, 2021). Through this rigorous process, students develop memories and knowledge related to the efficiency and effectiveness of playing tennis. Information is processed from both the teacher and the learning environment, creating diverse, meaningful, and contextual movement programs that enrich students’ knowledge, thus promoting critical thinking.

The findings of this study align with previous research, which suggests that physical activity directly affects brain function, and this effect subsequently enhances cognitive abilities (Hötting & Röder, 2013; Suwabe et al. 2017). This perspective underscores that engaging in physical activities leads to better cognitive function, facilitated through neurotransmitter activity (Lista & Sorrentino, 2010). Therefore, physical activity stimulates cognitive functions, leading to improved mental processing.

The study provides insights into a structured cognitive teaching approach that supports critical thinking development through physical education. It offers essential guidelines, emphasizing that physical education should engage mental procedures, develop models, test hypotheses, collect learning data, and interpret outcomes to demonstrate

desired movement tasks (Morales-Belando & Arias-Estero, 2017; Renshaw et al. 2016). Furthermore, trust and engagement are fostered through physical activities, such as discussions, which provide students with opportunities to express their thoughts, ideas, and feelings (Clark et al 2011; Hings et al. 2020). The study results show a positive correlation between physical activities in physical education and critical thinking skills, supporting previous research that emphasizes the need for teachers to employ both direct and indirect teaching methods. These methods should facilitate student learning through questioning, problem-solving, and critical thinking, while also enabling repeated practice of learned concepts (Donnelly et al. 1999; Kpazai et al. 2015).

Conclusions

Cognitive-reflective learning in physical education, through game-based or movement problem-situated approaches, effectively strengthens critical thinking skills. The study demonstrated that cognitive teaching in tennis and extracurricular futsal sessions had varying impacts on students’ ability to address critical thinking tasks. Specifically, 70% of critical thinking items showed a reduced level of difficulty among students participating in extracurricular futsal, compared to those engaged in cognitive tennis instruction. This finding underscores the potential of physical education to serve as a holistic educational approach that integrates intellectual value, provided that the instructional design actively promotes cognitive development. Moreover, it is essential to recognize that movement learning extends beyond physical activity; it also involves cognitive engagement. The integration of cognitive-reflective elements in physical education has been shown to enhance cognitive performance and function. Therefore, a strong relationship exists between movement tasks in physical education and the development of critical thinking skills. By intentionally designing physical education lessons to foster cognitive skills, educators can contribute meaningfully to the overall intellectual growth of students.

Conflict of Interest

The authors have no conflicts of interest to declare.

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Фізичне виховання на основі когнітивно-рефлексивного моторного навчання сприяє підвищенню здібностей до критичного мислення: Чи демонструє модель аналізу Раша значущі докази?

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів
Реферат. Стаття: 9 с., 4 табл., 5 рис., 41 джерело.

Історія питання. У цьому дослідженні розглядається питання необхідності підвищення когнітивно-рефлексивних компетентностей у фізичному вихованні, в якому часто надається пріоритет оволодінню базовими спортивними навичками за рахунок когнітивного розвитку. В інформаційну епоху критичне мислення є ключовою когнітивно-рефлексивною навичкою, яку необхідно розвивати.

Мета дослідження. Мета дослідження полягала у вивченні структурної моделі інструктивної дидактики та оцінці змін у рівнях складності критичного мислення серед учнів у контексті фізичного виховання.

Матеріали та методи. Застосовано посттестовий дизайн контрольної групи, в якому збір даних щодо критичного мислення проводився після занять з фізичного виховання. До дослідження було залучено дві групи: експериментальний клас, який інтегрував когнітивне навчання через теніс, та контрольний клас, який брав участь у позакласних заняттях з футболу, кожна з яких складалася з 30 учнів середньої школи (віком 13-14 років).

Результати. Аналіз результатів із застосуванням моделювання Раша виявив значні зміни в рівнях складності критичного мислення. Зокрема, показники критичного мислення, включаючи інференцію, розпізнавання припущень, дедуктивне міркування, інтерпретацію та оцінку аргументів, показали зниження складності на 70% для учнів експериментальної групи порівняно з учасниками контрольної групи.

Висновки. Отримані результати свідчать про те, що когнітивно-рефлексивне навчання у фізичному вихованні сприяє значному поліпшенню здібностей учнів до критичного мислення, оскільки учні експериментального класу демонструють кращі навички критичного мислення, ніж їхні однолітки з контрольної групи.

Ключові слова: фізичне виховання, когнітивно-рефлексивне навчання, критичне мислення, модель Раша, середня школа.

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The Mediating Role of Anthropometric Improvements in The Effects of Resistance Training on Speed, Strength, and Power in U20 Futsal Athletes

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Adolescence is characterized by heightened trainability, yet approximately 18 % of young people are overweight or obese. It has been noted that in five Yogyakarta futsal clubs, 37–51 % of U17 players show BMI $\geq 25 \text{ kg}\cdot\text{m}^{-2}$, potentially hampering performance.

Objectives. This study aimed to examine whether implementing an eight-week resistance-training programme enhances 20-m sprint speed, lower-body strength, and explosive power in U17 futsal athletes, and whether body fat change mediates these effects.

Materials and methods. Thirty 18-19-year-old male players completed periodised resistance sessions that were conducted on a thrice-weekly basis. Body mass, BMI, body fat percentage (BF %), sprint time, one-repetition-maximum leg press, and standing long-jump distance were measured in the pre-/post-intervention phase. Paired-sample t-tests were used to assess within-group changes. Mediation models (PROCESS; 5,000 bootstraps) examined whether ΔBF % transmitted the influence of ΔBMI on performance.

Results. A substantial decrease was observed in body mass (-1.21 kg), BMI ($-0.43 \text{ kg}\cdot\text{m}^{-2}$), and BF % (-1.48%), while sprint time (-0.95 s), leg-press strength ($+11.9 \text{ kg}$), and jump distance ($+11.8 \text{ cm}$) improved (all $p < .001$). ΔBMI predicted ΔBF % ($B = 5.38, p < .001$). BF % partially mediated the BMI–sprint link (indirect effect = 3.52, 95 % CI [2.70, 4.47]), although a significant direct path persisted. Mediation was non-significant for strength and power; BMI reduction showed no relation to strength change, yet retained a strong direct association with power gains independent of BF %.

Conclusions. The findings of this study indicate that resistance training markedly improves neuromuscular performance and body composition in youth futsal athletes. A lower BMI enhances sprint speed both directly and through concurrent reductions in BF %, whereas adaptations in strength and power arise through mechanisms other than adiposity. Training programmes should therefore combine neuromuscular loading with strategies for healthy weight management to optimise youth futsal performance.

Keywords: anthropometric, resistance training, speed, strength, power, futsal.

Introduction

In contemporary youth-athlete development, enhancing key physical capacities — strength, speed, and explosive power — has become a central objective across many

sports, including futsal. Futsal is a high intensity discipline that demands explosiveness, agility, and rapid acceleration within a confined playing area. Meeting these demands requires an optimal physical profile that supports dynamic and efficient play (Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008; Yulvia Miftachurochmah, Tomoliyus, & ER, 2023; Milanović et al., 2011). Resistance training is widely recommended to build such capacity and has been shown to improve muscular strength, explosive power, and

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sprint speed (Behringer, Vom Heede, Yue, & Mester, 2010; Faigenbaum et al., 2009).

Physiologically, adolescence is considered a golden age of trainability, marked by heightened adaptability to exercise stimuli. Hormonal and neuromuscular changes during this period accelerate training responses, making it strategically advantageous for optimizing physical development (Lloyd & Oliver, 2012; Malina, Rogol, Cumming, Coelho e Silva, & Figueiredo, 2015). Recent evidence confirms that structured, progressive resistance training programmes significantly enhance adolescent performance indicators such as muscular strength, sprint velocity, and jump height (Behm et al., 2017; Dias et al., 2023; Vesci, Webster, Sich, & Marinko, 2017). While biological maturation contributes to these gains, sport specific neuromuscular adaptations elicited by targeted training also play a decisive role. A parallel challenge has emerged with the global rise in adolescent overweight and obesity. Zhang et al. (2024) reported that approximately 18 % of individuals aged 5–19 years are overweight or obese, with faster growth rates in developing nations, including Indonesia. Preliminary observations in five futsal clubs within the Special Region of Yogyakarta indicated that 37–51 % of U20 players recorded a body mass index (BMI) $\geq 25 \text{ kg}\cdot\text{m}^{-2}$, suggesting excess body mass that may hinder optimal on court performance.

Body composition variables — particularly fat mass and fat free mass — are closely linked to athletic performance. In adult cohorts, excess body mass, especially elevated fat mass, increases mechanical load, reduces sprint efficiency, slows change of direction ability, and impairs acceleration (Bishop et al., 2007). Conversely, recent intervention studies demonstrate that reducing fat percentage can promote muscle mass accretion even within short training periods (Liu, Li, Lu, & Zhu, 2024). Relative increases in muscle mass further support improvements in strength and explosive power. Hence, programmes that favourably modify body composition are crucial for youth-performance enhancement.

Growing evidence underscores resistance training as a dual purpose intervention that simultaneously amplifies neuromuscular function (increasing strength, power, and speed) and remodels body composition (Behm et al., 2017; Lesinski, Prieske, & Granacher, 2016; Y Miftachurochmah, Sukamti, Arjuna, & Pamungkas, 2023). Yet few studies have examined whether anthropometric improvements actually mediate the link between resistance training and performance gains in late adolescent futsal athletes. Resolving this mechanism has immediate practical value for coaches designing evidence based programmes and tailoring workloads to players with sub optimal BMI or fat mass profiles. Accordingly, the present study investigated the effects of a 8 week resistance training programme on sprint speed, lower body strength, and explosive power in U20 futsal athletes. Crucially, it tested whether reductions in BMI and body fat percentage mediate the training performance relationship, thereby clarifying the pathways through which resistance training enhances on court readiness in this age group.

Materials and Methods

This study employed a quasi-experimental design with a pre-test and post-test approach conducted over an

eight-week period. The primary objective was to examine the mediating role of anthropometric improvements in the effects of resistance training on speed, strength, and explosive power among U20 futsal athletes. The intervention consisted of a structured resistance training program. Pre- and post-intervention assessments were conducted to evaluate changes in anthropometric parameters and physical performance outcomes. This research was approved by the Research Ethics Committee of Universitas Negeri Yogyakarta, registration number: T/36.1/UN34.9/KP.06.07/2024.

Study Participants

A total of 30 male futsal athletes aged 18-19 years participated in this study. Participants were recruited from five futsal clubs located in the Special Region of Yogyakarta, Indonesia. The inclusion criteria were as follows: (1) active participation in futsal training for at least one year, (2) no history of musculoskeletal injury within the past six months, and (3) a body mass index (BMI) between 25.1 and 29.9 at baseline assessment. The exclusion criteria included: (1) any medical condition contraindicating participation in resistance training, and (2) noncompliance with at least 80% of the scheduled training sessions. Written informed consent was obtained from all participants and their legal guardians prior to enrollment in the study.

Experimental Design

Prior to the intervention, participants underwent baseline assessments that included anthropometric measurements and physical performance tests. Anthropometric measurements were conducted first, followed by performance testing, with sufficient rest intervals between tests to minimize fatigue. All assessments were standardized and administered by the same team of evaluators to ensure consistency and reliability of the results. Following the initial assessment, participants engaged in a structured resistance training program for eight weeks while continuing their regular futsal training schedules. The resistance training sessions were conducted three times per week, with a minimum of 48 hours between sessions. Each session lasted approximately 60 minutes, consisting of 5-10 minutes of dynamic warm-up, 40-50 minutes of resistance training, and 5-10 minutes of cool-down. The program followed the principle of progressive overload, starting at moderate intensity (60% of one-repetition maximum, 1RM) and gradually progressing to high intensity (up to 80% of 1RM) in the final weeks. The resistance training exercises included both upper- and lower-body dominant movements, as detailed below outlining the training program. Participant attendance was recorded, and inclusion in the final analysis required participation in at least 80% of the training sessions. At the end of the intervention period, post-test assessments identical to the baseline evaluations were conducted to determine changes in anthropometric and physical performance variables.

Testing Procedure

Anthropometric measurements included assessments of body mass and height. Height was measured using a stadiometer with participants barefoot. Body mass index (BMI) and body fat percentage (BF) were estimated using a

bioelectrical impedance analyzer (Omron HBF 375, Tokyo, Japan), following standard pre-test conditions such as fasting and hydration control.

Physical performance testing was conducted to assess sprint speed, lower-body strength, and lower-body explosive power. Sprint speed was evaluated using a 20-meter sprint test, with timing recorded by three stopwatch operators. Each participant performed two sprint trials, and the fastest time was recorded as the final result. Lower-body strength was assessed using a one-repetition maximum (1RM) test on a leg press machine (Technogym), in accordance with standard maximal strength testing guidelines (Baechle & Earle, 2008). Following a warm-up, participants performed incremental lifts until they reached the maximum load they could lift once with proper technique. Lower-body explosive power was measured using the long broad jump test to assess horizontal jumping ability. Each participant completed three maximal-effort jumps, and the best distance achieved was recorded as the final result.

Statistical Analysis

Descriptive statistics were calculated for all variables and are presented as means and standard deviations. The normality of data distribution was assessed using the Shapiro–Wilk test. Paired-sample t-tests were conducted to analyze changes in anthropometric and physical performance variables between pre- and post-intervention measurements.

Furthermore, to examine the mediating role of anthropometric improvements (i.e., changes in BMI and body fat percentage) in the relationship between resistance training and improvements in sprint speed, muscular strength, and explosive power, a mediation analysis was performed using the PROCESS macro for SPSS (Model 4) developed by Hayes (2013). The significance of indirect effects was evaluated using a bootstrapping procedure with 5,000 resamples, and 95% bias-corrected confidence intervals (CIs) were reported. Indirect effects were considered significant if the confidence interval did not include zero. The level of statistical significance for all analyses was set at $p < .05$. All statistical analyses were performed using

IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA).

Results

Table 1 presents the descriptive statistics—including minimum, maximum, mean, and standard deviation—for each measured variable at both pre-test and post-test phases. The results show consistent trends reflecting the effectiveness of the resistance training intervention.

In terms of sprint performance, the average time for the 20-meter sprint decreased from 5.57 seconds (SD = 0.78) at pre-test to 4.62 seconds (SD = 0.89) at post-test, indicating improved speed. Leg strength, as measured by the leg dynamometer, increased from a pre-test mean of 110.08 kg (SD = 3.91) to 122.00 kg (SD = 5.31) at post-test. Similarly, explosive power — assessed via the long broad jump — increased from 180.27 cm (SD = 13.89) to 192.10 cm (SD = 13.65). Anthropometric measures also showed favorable changes. Body weight decreased from a mean of 73.07 kg (SD = 3.10) at pre-test to 71.86 kg (SD = 3.10) at post-test. Body mass index (BMI) decreased from 25.95 (SD = 0.65) to 25.52 (SD = 0.63), and body fat percentage declined from 26.97% (SD = 0.81) to 25.49% (SD = 0.86), indicating improvements in body composition following the intervention. Overall, these descriptive results reflect consistent improvements across both anthropometric and performance variables from pre- to post-intervention, supporting the effectiveness of the resistance training program. However, to statistically verify the effects of resistance training on these variables, further analysis using paired sample t-tests is required.

To fulfill the assumptions of the paired t-test, a normality test was conducted. The Shapiro–Wilk test was selected due to the sample size being fewer than 50 participants. The test was applied to all dependent variables at both pre-test and post-test stages. The results indicated that all p-values exceeded the significance threshold of .05, suggesting that none of the variables violated the assumption of normality. Detailed results of the normality test are presented in Table 2.

The results show that for the 20-meter sprint, the Shapiro–Wilk test indicated no significant deviation from

Table 1. Summary of Pre- and Post-Test Descriptive Statistics for All Study Variables

Variable			MIN	Max	Mean	SD
Performance Ability	20 m Sprint	Pre-Test	4.40	7.00	5.57	0.78
		Post-Test	3.13	6.13	4.62	0.89
	Leg Dynamometer	Pre-Test	102.50	117.50	110.08	3.91
		Post-Test	115.00	135.00	122.00	5.31
	Long Broad Jump	Pre-Test	159.00	210.00	180.26	13.89
		Post-Test	170.00	220.00	192.10	13.65
Antropometric	Body Weight	Pre-Test	65.00	78.00	73.07	3.095
		Post-Test	64.00	76.80	71.86	3.104
	BMI	Pre-Test	25.04	27.51	25.95	0.65
		Post-Test	24.53	26.92	25.52	0.63
	Body Fat	Pre-Test	25.50	28.90	26.97	0.81
		Post-Test	23.60	26.90	25.49	0.86

normality at either the pre-test ($W = 0.950$, $p = .165$) or post-test ($W = 0.979$, $p = .810$). Similarly, leg strength, as measured by the leg press machine, was normally distributed ($p = .108$ at pre-test and $p = .072$ at post-test). Long broad jump scores

Table 2. Results of the Shapiro–Wilk Normality Test for All Measured Variables

Variable		X	W	df	p
Performance Ability	20m Sprint	Pre-Test	0.950	30	0.165
		Post-Test	0.979	30	0.810
	Leg Dynamometer	Pre-Test	0.943	30	0.108
		Post-Test	0.936	30	0.072
	Long Broad Jump	Pre-Test	0.961	30	0.330
		Post-Test	0.959	30	0.284
Anthropometric	BMI	Pre-Test	0.956	30	0.242
		Post-Test	0.970	30	0.531
	Body Fat	Pre-Test	0.987	30	0.972
		Post-Test	0.977	30	0.744

also conformed to a normal distribution ($p = .330$ for pre-test and $p = .284$ for post-test). For the anthropometric measures, BMI values showed no significant deviation from normality ($p = .242$ for pre-test and $p = .531$ for post-test), and body fat percentage demonstrated strong normality at both time points ($p = .972$ for pre-test and $p = .744$ for post-test). These results support the use of parametric statistical procedures, such as paired sample t-tests, in subsequent analyses.

To evaluate the effectiveness of the resistance training intervention on anthropometric and performance outcomes, a series of paired sample t-tests were conducted to compare pre-test and post-test values across six key variables: body weight (BW), body mass index (BMI), body fat percentage (BF), 20-meter sprint time, leg press strength (LP), and long broad jump distance (LBJ). All difference scores were calculated as the mean difference between pre-test and post-test values (i.e., pre-test minus post-test), where positive values reflect a reduction (e.g., in body weight, BMI, and body fat percentage), and negative values indicate improvement in variables where higher post-test scores are desirable (e.g., strength and power). An exception applies to sprint time, where a positive value still represents improvement, as it

Table 3. Results of Paired t-Tests on Pre- and Post-Intervention Outcomes

Variable Pair	Pre-test Mean (SD)	Post-test Mean (SD)	Mean Difference	t	df	p	95% CI of Difference	Cohen's d
BW (kg)	73.07 (3.10)	71.86 (3.10)	1.21	25.32	29	< 0.001	[1.11, 1.31]	4.62
BMI	25.95 (0.65)	25.52 (0.63)	0.43	24.27	29	< 0.001	[0.39, 0.47]	4.56
BF (%)	26.97 (0.82)	25.49 (0.86)	1.48	14.72	29	< 0.001	[1.27, 1.68]	2.69
Sprint (sec)	5.57 (0.78)	4.62 (0.82)	0.95	10.81	29	< 0.001	[0.77, 1.13]	1.97
Leg Press (kg)	110.08 (3.91)	122.00 (5.31)	-11.92	-18.25	29	< 0.001	[-13.25, -10.58]	-3.33
LBJ (cm)	180.27 (13.89)	192.10 (13.65)	-11.83	-19.57	29	< 0.001	[-13.07, -10.60]	-3.57

Table 4. Mediating Role of Body Fat in the Relationship Between BMI and Physical Performance Outcomes

Outcome	Mediation Path	B (Raw)	β (Std.)	SE	p	95% CI (LLCI, ULCI)
Speed	$\Delta\text{BMI} \rightarrow \text{BF}$ (a path)	5.3776	0.9513	0.3292	<0.001	[4.7033, 6.0520]
	$\Delta\text{Body Fat} \rightarrow \Delta\text{Sprint}$ (b path)	0.6537	0.7474	0.0490	<0.001	[0.5532, 0.7541]
	$\Delta\text{BMI} \rightarrow \Delta\text{Sprint}$ (Direct effect c')	1.2754	0.2580	0.2767	<0.001	[0.7076, 1.8433]
	Indirect Effect ($a \times b$)	3.5152	0.7110	0.4491*	–	[2.7043, 4.4704]†
	Total Effect of ΔBMI on ΔSprint	4.7907	0.9690	0.2309	<0.001	[4.3176, 5.2637]
Strength	$\Delta\text{BMI} \rightarrow \Delta\text{BF}$ (a path)	5.38	0.951	0.33	<0.001	[4.70, 6.05]
	$\Delta\text{BF} \rightarrow \Delta\text{Strength}$ (b path)	3.79	0.582	3.94	0.344	[-4.28, 11.87]
	$\Delta\text{BMI} \rightarrow \Delta\text{Strength}$ (Direct effect)	-13.94	-0.379	22.25	0.536	[-59.59, 31.71]
	Indirect effect ($a \times b$)	20.39	0.554	20.20*	–	[-19.31, 60.94]†
	Total Effect of ΔBMI on $\Delta\text{Strength}$	6.4528	0.1753	6.8472	0.354	[-7.5734, 20.4791]
Power	$\Delta\text{BMI} \rightarrow \Delta\text{BF}$ (a path)	5.38	0.951	0.33	<0.001	[4.70, 6.05]
	$\Delta\text{BF} \rightarrow \Delta\text{Power}$ (b path)	-0.06	-0.011	0.84	0.940	[-1.80, 1.60]
	$\Delta\text{BMI} \rightarrow \Delta\text{Power}$ (Direct effect)	-32.87	-0.964	4.77	<0.001	[-42.65, -23.08]
	Indirect Effect ($a \times b$)	-0.35	-0.010	4.72*	–	[-9.42, 8.87]†
	Total Effect ($\Delta\text{BMI} \rightarrow \Delta\text{Power}$)	-33.21	-0.975	1.44	<0.001	[-36.17, -30.26]

Note. B = unstandardized coefficient, β = standardized coefficient, SE = standard error, CI = confidence interval.

*Bootstrapped SE; † Bootstrapped 95% confidence interval with 5000 samples. Δ indicates post-test minus pre-test values; higher ΔSprint , $\Delta\text{Strength}$, and ΔPower reflect performance improvement. BMI = Body Mass Index; BF = Body Fat Percentage.

indicates a reduction in the time required to complete the 20-meter sprint, denoting enhanced performance. The detailed results of the paired sample t-tests are presented in Table 3 below.

Results showed a significant reduction in body weight, $t(29) = 25.32$, $p < .001$, with an average loss of 1.21 kg (95% CI [1.11, 1.31]). Body mass index (BMI) also significantly declined, $t(29) = 24.27$, $p < .001$, by an average of 0.43 units (95% CI [0.39, 0.47]). Likewise, body fat percentage decreased significantly, $t(29) = 14.72$, $p < .001$, with a mean reduction of 1.48% (95% CI [1.27, 1.68]). Sprint performance improved, as evidenced by a significant decrease in 20-meter sprint time, $t(29) = 10.81$, $p < .001$, with an average reduction of 0.95 seconds (95% CI [0.77, 1.13]). For performance variables where increased values indicate improvement, significant gains were observed. Leg press strength increased by an average of 11.92 kg, $t(29) = -18.25$, $p < .001$ (95% CI [-13.25, -10.58]). Similarly, long broad jump distance improved significantly, $t(29) = -19.57$, $p < .001$, with an average increase of 11.83 cm (95% CI [-13.07, -10.60]). These findings indicate that the resistance training program was effective in producing statistically and practically significant improvements in body composition, muscular strength, and power, as well as in sprint performance.

Since all participants received the same treatment (resistance training), the independent variable does not vary. In this context, anthropometric changes — specifically body mass index (BMI) and body fat percentage (BF) — are regarded as reflections of the intervention effect and are therefore treated as proxies to model their downstream impact on physical performance outcomes. A series of mediation analyses were conducted using PROCESS Model 4 (Hayes, 2022) to examine whether changes in body fat percentage (ΔBF) mediated the effect of changes in body mass index (ΔBMI) on improvements in sprint performance ($\Delta Sprint$), muscular strength ($\Delta Strength$), and explosive power ($\Delta Power$). All change scores were computed as post-test minus pre-test values. The detailed results of the PROCESS Model 4 analyses are presented in Table 4 below.

The results showed that ΔBMI significantly predicted ΔBF ($B = 5.38$, $SE = 0.33$, $p < .001$), and ΔBF significantly predicted $\Delta Sprint$ performance ($B = 0.65$, $SE = 0.05$, $p < .001$), indicating a positive relationship between reductions in body composition and improvements in sprinting ability. The direct effect of ΔBMI on $\Delta Sprint$ also remained significant ($B = 1.28$, $SE = 0.28$, $p = .0001$), suggesting partial mediation. The indirect effect via ΔBF was significant ($B = 3.52$, Boot $SE = 0.45$, 95% CI [2.70, 4.47]), indicating that reductions in BMI enhanced sprint performance both directly and indirectly through decreases in body fat percentage.

For muscular strength, although ΔBMI significantly predicted ΔBF ($B = 5.38$, $SE = 0.33$, $p < .001$), the path from ΔBF to $\Delta Strength$ was not significant ($B = 3.79$, $SE = 3.94$, $p = .344$). The direct effect of ΔBMI on strength was also non-significant ($B = -13.94$, $SE = 22.25$, $p = .536$), as was the total effect ($B = 6.45$, $SE = 6.85$, $p = .354$). Similarly, the indirect effect through ΔBF was non-significant ($B = 20.39$, Boot $SE = 20.20$, 95% CI [-19.31, 60.94]), indicating no evidence for either a direct or mediated effect of ΔBMI on lower-body strength in this sample.

In the model assessing power, ΔBMI again significantly predicted ΔBF ($B = 5.38$, $SE = 0.33$, $p < .001$). However, ΔBF

did not significantly predict $\Delta Power$ ($B = -0.06$, $SE = 0.84$, $p = .940$), and the indirect effect was non-significant ($B = -0.35$, Boot $SE = 4.72$, 95% CI [-9.42, 8.87]). Despite this, the direct effect of ΔBMI on $\Delta Power$ remained highly significant ($B = -32.87$, $SE = 4.77$, $p < .001$), and the total effect was also significant ($B = -33.21$, $SE = 1.44$, $p < .001$), indicating a strong direct association between reductions in BMI and improvements in explosive power, independent of body fat percentage.

These findings suggest that body fat percentage mediates the relationship between BMI reduction and sprint performance, but not between BMI and either muscular strength or explosive power. Although changes in BMI were associated with improvements in power, body fat percentage did not serve as a significant mediator, suggesting that other physiological or biomechanical mechanisms may be involved.

Discussion

This study aimed to examine the effects of an eight week resistance training programme on speed, strength, and power in youth futsal athletes and to evaluate whether anthropometric changes — specifically body mass index (BMI) and body fat percentage (BF%) — mediated those effects. The programme produced marked improvements in 20 m sprint speed ($t_{(29)} = 10.81$, $p < .001$, 95% CI [-1.13, -0.77]), lower body strength ($t_{(29)} = -18.25$, $p < .001$, 95% CI [+10.58, +13.25]), and explosive power ($t_{(29)} = -19.57$, $p < .001$, 95% CI [+10.60, +13.07]). Concurrently, body weight decreased by 1.21 kg ($t_{(29)} = 25.32$, $p < .001$, 95% CI [-1.31, -1.11]), BMI by 0.43 units ($t_{(29)} = 24.27$, $p < .001$, 95% CI [-0.47, -0.39]), and BF% by 1.48 percentage points ($t_{(29)} = 14.72$, $p < .001$, 95% CI [-1.68, -1.27]). Mediation analyses further revealed that these anthropometric improvements explained a substantial portion of the gains in sprint performance but not those in strength or power. These findings confirm the dual pathway by which resistance training enhances athletic performance—through direct neuromuscular adaptations and, for speed, through favourable shifts in body composition—while also highlighting that additional mechanisms are likely responsible for strength and power related outcomes.

The findings indicate that every decrement in body mass index (BMI) is accompanied by a proportional reduction in body fat percentage (BF%) and that these concurrent changes are associated with shorter 20 m sprint times. This pattern matches evidence from adolescent footballers, in whom BF% shows the strongest negative correlations with 5–35 m sprint performance ($r = 0.25$ – 0.52 ; França et al., 2024). Mechanically, adipose tissue acts as non propulsive mass: unloading 5–10 % of body weight with body weight-support devices shortens ground contact time and braking impulse per step, thereby enhancing initial acceleration (Kratky & Müller, 2013). A lighter body also reduces phosphocreatine cost per metre travelled, enabling athletes to sustain high power output over short distances (di Prampero, Botter, & Osgnach, 2015).

Speed, however, is not determined solely by adiposity. The resistance training programme that lowered BMI elicited rapid neuromuscular adaptations—greater motor

unit recruitment, higher discharge rates, and improved synchronisation (Sterczala et al., 2020) — which are typically detectable within 6–8 weeks in adolescents (Del Vecchio et al., 2019; Herda et al., 2024). These neural changes elevate the rate of force development (Maffiuletti et al., 2016) and, together with post training increases in tendon stiffness (Waugh, Korff, Fath, & Blazevich, 2014), allow maximal propulsive force to be generated earlier during each ground contact (Tumkur Anil Kumar, Oliver, Lloyd, Pedley, & Radnor, 2021). In essence, a lighter body minimises mechanical drag, whereas neuromuscularly “primed” muscle–tendon units augment explosive capacity; the interaction of these pathways explains why BMI reductions enhance sprint performance both directly and through adiposity loss in overweight adolescent futsal players.

The observation that changes in BMI and body fat percentage did not correlate with improvements in leg press strength is consistent with the known time course of strength adaptation. During the first 6–8 weeks of training, increases in maximal leg press load are driven almost entirely by neuromuscular mechanisms: the central nervous system recruits more motor units, fires them at higher frequencies, and better synchronises agonist–antagonist activity. Time course reviews confirm that more than 80 % of the strength gained within 2–8 weeks derives from motor unit recruitment, synchronisation, and neural drive, irrespective of adiposity status (Bontemps et al., 2022). Likewise, body fat has been shown to be unrelated to — and a poor predictor of — muscle strength (Choi, Kim, Hur, & Lee, 2016).

In the present study, the decline in BMI chiefly reflected a loss of adipose tissue rather than an enlargement of the thigh or gluteal cross sectional area that actually produces force in the leg press. Schranz et al (2013) similarly reported large strength gains after resistance training without substantial changes in body composition. Overall, such interventions tend to produce only small changes in body composition yet moderate to large improvements in strength among overweight and obese children and adolescents (Schranz, Tomkinson, & Olds, 2013). Myers et al (2017) reached the same conclusion in overweight adolescents. The absence of a body fat–mediated pathway for strength gains may also reflect the programme’s emphasis on moderate loads executed rapidly and repeatedly, a stimulus that provides insufficient mechanical tension to induce hypertrophy or appreciable fibre accretion. In overweight youths, therefore, fat loss reduces inertial ballast and benefits explosive tasks such as sprinting, but it does not enhance the contractile capacity that determines leg press performance.

Interestingly, the present data show that a reduction in body mass index (BMI) is directly associated with greater explosive power, although the concomitant decline in body fat percentage (BF%) does not mediate this effect. Excess body weight generally impairs explosive performance: Nikolaidis et al. (2015) reported that overweight adolescent basketball players — characterised by higher BMI and BF% — exhibited poorer sprint and jump outcomes (vertical and broad jump) than their normal weight counterparts, indicating that surplus mass, particularly fat, adds non propulsive load and worsens the force to mass ratio. In contrast, other observational studies suggest that BF% is usually the stronger negative predictor of jump performance, whereas BMI is often non significant (Esco et al., 2018). For

example, among adolescent soccer players, BMI showed no meaningful correlation with vertical jump height, whereas BF% was strongly and negatively related to jump performance (Stojanović et al., 2020). Similar results have been reported in combat sport athletes, where BF% correlated negatively with jump height while body mass and BMI did not (Abidin & Adam, 2013). Nevertheless, the influence of BMI and BF% on power warrants further investigation, as power is understood to be driven primarily by strength and speed (Yulvia Miftachurochmah, Tomoliyus, Sukanti, Pamungkas, & Pavlović, 2023).

Multiple studies emphasise that neuromuscular adaptations — particularly increases in the rate of force development (RFD) — and mechanical factors are critical to improvements in explosive power. Strength or plyometric training elevates RFD and inter muscle coordination, enabling higher jump performance without necessarily altering body composition. Lamas et al. (2012) showed that eight weeks of either heavy strength or high velocity power training increased squat jump height by 4–8 cm, driven by a significantly faster concentric phase and a 24–42 % rise in peak rate of force development, underscoring that rapid force production is a stronger determinant of jump performance than body mass alone. Given the complex interplay among body composition (BMI and BF%), strength, and speed in determining power, the current data are insufficient to claim that BMI reduction alone predicts explosive performance. The observed gains in power are most likely influenced by concurrent improvements in strength and sprint speed — variables not analysed separately in this study. Follow up research that measures strength, speed, and detailed body composition changes is required to map the relative contributions of each factor to explosive ability.

In summary, resistance training elicits two partially independent physiological cascades that together explain the pattern observed in the present study. Although the current investigation cannot directly delineate the physiological mechanisms underlying the measured outcomes, plausible explanations can be inferred from the extant literature. The first cascade in resistance training adaptation is neuromuscular–mechanical. Within weeks, heavy load work lowers motor unit recruitment thresholds, elevates firing frequency, and enhances inter unit synchronisation while reducing antagonist co activation (Del Vecchio et al., 2019; Häkkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Hughes, Ellefsen, & Baar, 2018). Concurrent increases in musculotendinous stiffness shorten the electromechanical delay and improve the stretch–shortening cycle (Waugh et al., 2014). These neural adaptations raise maximal force, accelerate the rate of force development, and reduce ground contact time, thereby driving the notable gains in lower body strength, explosive power, and 20 m sprint speed recorded in the present cohort — even before appreciable hypertrophy occurs (Blazevich, Wilson, Alcaraz, & Rubio-Arias, 2020; Del Vecchio et al., 2019; Hughes et al., 2018). With continued training, modest increases in fascicle cross sectional area further augment the “engine” for force production and reinforce the direct association between the observed body composition improvements and power gains (Monti et al., 2020; Zemková et al., 2017).

The second cascade is metabolic–endocrine and operates largely in parallel with, rather than through, the neuromuscu-

lar pathway. Resistance training has been shown to aid weight loss across diverse populations, depending on the methods employed (Lopez et al., 2022; Pamungkas, Rismayanthi, Nasrulloh, & Arjuna, 2024). Appropriately prescribed resistance training elevates excess post exercise oxygen consumption (Greer, O'Brien, Hornbuckle, & Panton, 2021; Kirk et al., 2009), increases sympathetic catecholamines and growth hormone (Athanasίου, Bogdanis, & Mastorakos, 2023; Manini et al., 2012), and adds energetically costly lean tissue, together raising 24-hour energy expenditure and promoting net fat oxidation (Aristizabal et al., 2015). These shifts explain the significant reductions in BMI and body fat percentage observed in the present study. Because lighter limbs incur lower inertial and braking forces, the decline in body fat partially mediated the sprint improvement yet had minimal influence on strength and power, for which force production capacity — rather than body mass — remained the primary limiter. In summary, resistance training enhances speed, strength, and power through rapid neuromuscular and subsequent morphological adaptations while simultaneously lowering BMI and body fat via metabolic mechanisms; the divergent contributions of these cascades are mirrored in the variable specific mediation pattern identified by the PROCESS analysis.

Practically, these results show that a structured resistance training programme performed three times per week under qualified supervision is an effective strategy for improving speed, strength, explosive power, and body composition in youth futsal athletes. Managing key anthropometric variables — particularly BMI and body fat percentage — can enhance movement efficiency and on court explosiveness while reducing injury risk associated with unfavourable body composition. Theoretically, this study extends current knowledge by demonstrating that anthropometric improvements partially mediate the training–performance relationship, underscoring the need to integrate body composition monitoring into athletic development models for adolescents.

This study employed a one group pre test–post test design without a control group, thereby limiting causal inference. The small sample ($n = 30$), consisting exclusively of male athletes from five club in one geographic region, restricts generalisability to other athletic populations, particularly female or recreational players. The eight week intervention may have been insufficient to capture slower morphological adaptations such as muscle hypertrophy and tendon remodelling. Body composition assessment was limited to BMI and body fat percentage—indices that do not distinguish lean from fat mass — and was performed with bioelectrical impedance analysis, which has an estimated error of $\pm 3.5\%$. Test reliability for the performance measures (leg press, broad jump, 20 m sprint) may have been affected by learning effects despite the inclusion of a familiarisation session. Nutritional intake and physical activity outside the training sessions were not rigorously monitored.

Future research should employ a randomised controlled design with larger sample sizes, longer intervention periods, and more precise body composition techniques such as dual energy X ray absorptiometry or segmental bioelectrical impedance analysis. Investigating a range of resistance training modalities (e.g., plyometric or high velocity protocols) and stratifying analyses by biological maturation status would further clarify the adaptive responses of youth athletes to training stimuli.

Conclusions

This study demonstrated that a structured resistance training program significantly improved sprint speed, muscular strength, and explosive power in U20 futsal athletes, accompanied by reductions in body mass index (BMI) and body fat percentage. Anthropometric improvements, particularly the reduction in body fat, were shown to mediate the relationship between BMI and sprint performance. However, no such mediating effect was observed in relation to strength or power. While BMI reductions were associated with improvements in power, this relationship appeared to be independent of changes in body fat, suggesting that other physiological mechanisms may be involved. Similarly, the link between BMI and strength gains was not statistically supported either directly or through body fat, indicating a weaker or more complex relationship in that domain. These findings highlight the complex but meaningful role of body composition — particularly body fat percentage — in mediating the effects of resistance training on specific performance outcomes such as sprint speed. Despite these promising results, the study has several limitations, including the absence of a control group, a relatively small sample size, and reliance on basic anthropometric measures, namely body fat percentage. Therefore, future research is recommended to adopt an experimental design with a control group, a larger sample size, and more advanced techniques for assessing body composition to enhance the generalizability and validity of the findings.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Медіативна роль антропометричних поліпшень у впливі силових тренувань на швидкість, силу та потужність футзалістів вікової категорії U20

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 4 табл., 48 джерел.

Історія питання. Період підліткового віку характеризується здатністю організму до підвищених тренувальних навантажень, проте приблизно 18 % молодих осіб мають надлишкову вагу або страждають на ожиріння. Відзначено, що в п'яти футзальних клубах Джок'якарти 37–51 % гравців віком до 17 років мають $IMT \geq 25 \text{ кг} \cdot \text{м}^{-2}$, що потенційно негативно впливає на результативність.

Мета дослідження. Мета цього дослідження полягала у вивченні питання, чи сприяє впровадження восьми тижневої програми силових тренувань підвищенню показників швидкості спринту на 20 метрів, сили нижньої частини тіла та вибухової сили у футзалістів віком до 17 років, а також чи є зміна вмісту жирової маси в організмі чинником, що впливає на зазначені ефекти.

Матеріали та методи. Тридцять 18-19-річних гравців чоловічої статі виконували періодичні силові тренування, які проводилися тричі на тиждень. У перед- та постінтревенційній фазі дослідження вимірювалися показники маси тіла, ІМТ, відсоток жирової маси тіла (ВЖМТ), час спринту, максимальне навантаження під час виконання жиму ногами при одному повторенні та відстань стрибка в довжину з місця. З метою оцінки змін у групі застосовано парні t-критерії. Медіативні моделі (PROCESS; 5000 бутстрепів) досліджували, чи є зміни показників ВЖМТ опосередкованим фактором впливу змін ІМТ на результативність.

Результати. Спостерігалось суттєве зниження показників маси тіла (-1.21 кг), ІМТ ($-0.43 \text{ кг} \cdot \text{м}^{-2}$), а також відсоткового вмісту жиру в організмі (-1.48%), тоді як показники часу спринту (-0.95 с), сили ніг під час виконання жиму ($+11.9 \text{ кг}$) та відстань стрибка ($+11.8 \text{ см}$) покращилися (усі показники $p < 0.001$). Зміни показників ІМТ передбачали варіації ВЖМТ ($B = 5.38, p < 0.001$). Рівень ВЖМТ частково опосередковував зв'язок між ІМТ та спринтом (непрямий ефект = $3.52, 95 \% \text{ ДІ } [2.70, 4.47]$), однак із збереженням значної прямої траєкторії. Медіація не мала істотного значення для показників сили та потужності; зниження ІМТ не виявило жодного зв'язку зі зміною сили, продемонструвавши при цьому сильний прямий зв'язок із підвищенням потужності незалежно від відсотка жирової маси тіла.

Висновки. Результати цього дослідження показують, що силові тренування суттєво покращують нервово-м'язову працездатність та композицію тіла у юних футзалістів. Нижчий рівень ІМТ сприяє підвищенню швидкості спринту як безпосередньо, так і через паралельне зниження відсотка жирової маси тіла, тоді як адаптація показників сили та потужності відбувається за допомогою механізмів, відмінних від ожиріння. Тому тренувальні програми повинні поєднувати нервово-м'язове навантаження зі стратегіями здорового контролю ваги з метою оптимізації результативності юних футзалістів.

Ключові слова: антропометрія, силові тренування, швидкість, сила, потужність, футзал.

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The Relationship between Physical Activity and Academic Achievement in Primary School Pupils with Hearing Impairment

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Hearing impairment is one of the most frequently occurring diseases in children, both congenital and acquired. It affects approximately 1 to 3 children in every 1000 (Seifert et al., 2005).

Objectives. This study aimed to reveal the impact of physical activity on the mathematics achievement of primary school pupils with hearing impairments.

Materials and methods. The Children's Physical Activity Questionnaire (Corder et al., 2009) was used, which is based on the Children's Leisure Activities Study Survey questionnaire, which includes activities explicit to little children, such as "playing in a playhouse". The Mathematics Progress Monitoring Test (MPMT) (Kliziene et al., 2024) was adapted for pupils with hearing impairment. The MPMT was used to assess the mathematics achievement of the students who took part in the study. They were designed to evaluate each pupil's achievement level, which, according to the general curriculum, was divided into unsatisfactory, satisfactory, basic, and advanced. The mathematics achievement of pupils with hearing impairment was assessed in four areas of the mathematics curriculum.

Results. The posttest results of first-grade primary school pupils with hearing impairments (158.95 MET, min/week) were analyzed to compare average physical activity with the pretest results (125.61 MET, min/week), during physical education lessons. Walking to school (20.39 MET, min/week) and cycling to school (16.85 MET, min/week) showed statistically significant differences (between types of physical activity) in the pretest and posttest according to MET $p < 0.05$. PA helped pupils with hearing impairment to achieve basic results (pretest (5.81 (3.25) posttest (16.84 (2.98); $p = 0.000$) and advanced results (pretest (0.81 (0.53) posttest (4.18 (0.47); $p = 0.002$).

Conclusions. According to the findings, it was established that properly interpreted and appropriately applied physical activity for primary school pupils with hearing impairment led to statistically significant changes in dependent variables: an increase in pupils' physical activity and academic achievement. Marked changes were observed in mathematics tasks that required higher-level thinking skills, knowledge, and understanding; distribution of mathematics learning achievement by content such as natural and integer numbers, patterns and relationships, geometry and measurements, data, and statistical probabilities. Higher levels of physical activity resulted in achievement levels changing from satisfactory to basic and advanced.

Keywords: physical activity, achievement in mathematics, learners with hearing impairment.

Introduction

Hearing impairment is one of the most frequently occurring diseases in children, both congenital and acquired. It affects approximately 1 to 3 children in every 1000 (Seifert et al., 2005). Hearing impairment is an invisible disability, which can be invisible or overlooked by the teacher, or sometimes the child may deliberately hide it. The teacher

may assume that everything is fine, even if the pupil has difficulty hearing (Powell et al., 2014). This can lead to a strange situation: a child has skills and abilities but cannot use them because he or she cannot hear instructions. This can lead to pupils achieving poorly (Punch, Hyde, 2011). Even if hearing conditions are optimal during lessons, noisy breaks or lunch breaks can cause communication problems.

Compared to hearing children, pupils with hearing impairment have been found to have lower motor skills and physical fitness, which can have a negative impact on their engagement in physical activity (PA) and active lifestyles (Martin et al., 2013).

Therefore, the research questions were formulated as follows: What is the physical activity level of primary school pupils with hearing impairments? How does physical activity contribute to the achievement of primary school pupils with hearing impairments in mathematics?

The aim of the research: is to reveal the impact of physical activity on the mathematics achievement of primary school pupils with hearing impairments.

There are few studies that have looked at the engagement of deaf pupils with hearing impairment of hearing pupils in PA. This knowledge will be of great importance to policymakers and researchers to implement effective disease prevention.

Physical Activity of Primary School Pupils with Hearing Impairment. Physical activity (PA) is important for the development of children with hearing impairment (Xu et al., 2020). A meta-analysis found that physically active school-age children with hearing impairment have a better quality of life than sedentary learners (Kitterick et al., 2015). The World Health Organisation (WHO) has recommended that children and adolescents with and without disabilities should engage in at least 60 minutes of physical activity every day (World Health Organization, 2020). However, it is established, that only 20% of boys, girls, and adolescents with hearing impairment have been found to meet the World Health Organisation recommendation to engage in 60 minutes of physical activity daily (Li et al., 2019). Martínez et al. (2022) study found that PA was higher during school recess than during physical educational lessons among hearing-impaired pupils. Established, that facilitating the attendance of pupils with hearing impairment in physical education lessons requires strategies that address different aspects of the same lesson. Successful strategies were actions that had an educational purpose, achieved the pupil's functionality, and considered the pupil's qualities, needs, and capabilities (Kashuba et al., 2020).

Physical Activity and Mathematics Achievement for Pupils with Hearing Impairment. Research suggests a positive relationship between physical activity and academic achievement for primary school pupils, including those with hearing impairments. Studies have found that sports participation can significantly improve academic performance in hearing-impaired children (Ahmed et al., 2020). For students with hearing impairments, motivation to engage in physical education is positively correlated with learning outcomes (Nugraha, et al., 2019).

Research on the use of physical activity to increase mathematics learning among students with hearing impairments has covered different aspects. Overall, these research studies emphasize the importance of integrating physical activity to improve the mathematics learning experience of pupils with hearing impairments, their overall engagement in the learning process, and a particular focus on improving physical abilities and increasing physical activity. However, there is not much research on this in the field of special education.

Materials and Methods

Participants

All First-Grade students with hearing impairment who were studying in Lithuanian deaf and hard-of-hearing education centers participated in the experiment. In 2022–

2023, there were 13 pupils in the first grade in specialised deaf education institutions in Lithuania. Another criterion that was applied to the subjects was that students have been studying according to the general education program. Two pupils out of the selected 13 followed individualized education programs; therefore, only 11 students participated in this study (n = 11, including 6 boys and 5 girls).

The Evaluation of Physical Activity

The Children's Physical Activity Questionnaire (Corder et al., 2009) was utilized, which is based on the Children's Leisure Activities Study Survey (CLASS) questionnaire, which includes activities explicit to little children, such as "playing in a playhouse." The original intent of the proxy-reported CLASS questionnaire for 6–9-year-olds was to evaluate the type, recurrence, and intensity of physical activity over a standard week (Corder et al., 2009).

Mathematics Progress Monitoring Test

The Mathematics Progress Monitoring Test (MPMT) (Kliziene et al., 2024) was adapted for pupils with hearing impairment.

The MPMT was used to assess the mathematics achievement of the students who took part in the study. They were designed to assess each pupil's achievement level, which, according to the general curriculum, was divided into unsatisfactory, satisfactory, basic and advanced. The mathematics achievement of pupils with hearing impairment was assessed in four areas of the mathematics curriculum (General Curriculum Framework for Pre-primary, Primary and Secondary education (Order No V-1269 of the Minister of Education, Science and Sport of 24 August 2022; Kliziene et al., 2024) (Table 1):

Based on the test matrix, the mathematics content, the cognitive ability content groups and the pupils' levels of achievement in each area of the study, a maximum score was calculated to assess each pupil's achievement in a specific area of MPMT. To ensure equal evaluation of each pupil's MPMT results according to the fields of activity, MPMT evaluation instructions were used, and the limits of pupils' achievement levels were defined based on the MPMT characteristics (unsatisfactory, satisfactory, basic, advanced).

As defined in the MPMT profile, the level of achievement at the advanced level is 26–33 standard points on MPMT tasks; at the basic level, 12–25 standard points; at the satisfactory level, 5–11 standard points; and at the unsatisfactory level, 0–4 standard points (Kliziene et al., 2024).

Procedure

This study used a pretest and posttest methodology. Pupils with hearing impairments were assessed over a period of three months. A physical activity program was developed and a model of educational factors promoting physical activity among children was constructed.

Methodological materials for the physical activity program were also developed (Kliziene et al., 2021; Corder et al., 2009). The methodology was based on dynamic exercises, intensive repetition of motor skills, differentiation, reduction of the number of sitting and standing places, and

Table 1. Mathematics Curriculum content

Content of teaching(s)	
Natural and integer numbers	Numbers from 0 to 100. Addition and subtraction. Can read and write natural numbers up to 100, compare them, add and subtract two-digit numbers, perform addition and subtraction operations and solve simple real-world problems Financial calculations. Can analyse situations and solve problems that ask them to compare the prices of two goods (more expensive, less expensive), find the total price of goods in euros, and cents (within the euro limit), compare how much money has changed and what can be bought with the money available.
Patterns and relationships	Can use drawings, words and symbols to represent algorithms, and can represent a sequence of commands in a flow diagram.
Geometry and measurements	Measurement scales and units. Can be expressed as a number of length units. Can carry out a variety of practical tasks to get a feel for the mass of objects in the immediate environment that are or are not suitable for describing a unit of measurement. Figures. Can identify and correctly name simple geometric planes and figures; knows their names; apply existing knowledge of geometric planes and figures; can solve simple problems
Data and statistical probabilities	understands how data is presented, knows how to collect it, can read the information in a bar chart and can plot it on a graph based on data from the condition.
Cognitive ability groups	
Mathematical knowledge	The pupil is able to understand the concepts and perform standard mathematical procedures based on them.
Understanding	The learner is able to correctly understand and use the terms of the problems to solve the problems.
Applying mathematics and higher-thinking skills	The learner is able to solve more advanced problems, which are more difficult problems that are more procedural and have several possible strategies; the learner is able to choose and apply a strategy to solve the problem correctly.

Table 2. Physical activity program prepared according to the DIDSPA model for pupils with hearing impairments

	DIDSPA	Topic	Areas of Activity
Dynamic exercise	Aerobic capacity and/or muscle strength training. Physical activity can be any movement that improves physical well-being. Physical activity that provides more energy or endurance is usually referred to as aerobic activity.	Long jump-rope. Activity games. The long jump test to test the explosive power of children's leg muscles	Movement skills Movement skills Sports units (athletics)
Intensive repetition of motor skills	Reducing/eliminating queues so that children do not have to wait for their turn; small team games or group activities, e.g., 3 against 3 (this increases the number of times children can practice/apply their skills, – this helps to prevent children from being left on the sidelines or excluded from the game/activity); and increasing the amount of equipment available to children and/or increasing the number of stations.	Muscle stretching. Attempt to keep balance. Outdoor activity. Activity games. Jumping on two feet. Shuttle running 3 × 10 m.	Unconventional physical activity Sports units (athletics)
Differentiation	All children should be given tasks appropriate to their physical, emotional, and social situation that encourage them to participate actively in the learning process. Teachers should ensure that they are familiar with the space, tasks, equipment, and structure for the dynamic differentiation of activities.	Spider and turn. Animal aerobics. Children's Yoga.	Unconventional physical activity
Reduction of the number of sitting and standing places / Physical activity distribution in the classroom	When a teacher provides feedback questions to pupils, they do not need to stop the whole class, but can simply focus on a group of pupils or an individual child and pause their work. Engage children in the activity promptly, at the beginning of the exercise, by asking short questions and providing feedback. Ensure that equipment is ready, adjusted, and available at the beginning of and during the exercise.	Long jump-rope. The long jump test to test explosive power of children's leg muscles. Shuttle running 3 × 10 m.	

the model of physical activity distribution in the classroom (DIDSPA) (Powel et al., 2016) (Table 2).

Research Ethics

On February 6, 2023, the researchers received approval to conduct the investigation in accordance with protocol No. M4-2023-03. The heads of the educational institutions participating in the study and the parents of the participating students were informed about the purpose and course of the study. They were presented with the informed consent forms approved by the KTU Scientific Research Ethics Commission, in which all detailed information was included. The most important ethical principle of this study was to ensure the confidentiality of the participating pupils; therefore, no personal data of the students are presented in the study, and full pseudonymization of personal data is ensured.

Statistical Analysis

Descriptive statistics were reported for all measured variables as mean $\pm$ SD. The effect size of the Mann–Whitney U test was calculated using the equation $r = Z/\sqrt{N}$, in which Z is the z-score and N is the total number of the sample (small: 0.1; medium: 0.3; large: 0.5). Statistical significance was defined as $p \leq 0.05$ for all analyses. Analyses were conducted using SPSS 23 software (SPSS inc., Chicago, IL, USA).

Results

Physical Activity of Primary School Pupils with Hearing Impairment

Table 3 presents the results of the PA of first-grade primary school pupils with hearing impairments (pretest/posttest).

Table 3. Physical activity of primary school pupils with hearing impairment

Type of physical activity	MET	1 day/min	Days per week	MET, min/week
pretest				
Physical Education lesson	3.5	30	3	125.61
Cycling to school	4	0.57	2	12.67
Walking to school	3.3	0.70	3	13.27
Sport groups (mean physical activity)	6	60	1	921.08
On average for one first grade pupil with hearing impairment				1077.63*
posttest				
Physical Education lesson	3.5	30	3	158.95
Cycling to school	4	0.57	2	16.85
Walking to school	3.3	0.70	3	20.39
Sport groups (mean physical activity)	6	60	1	1105.93
On average for one first grade pupil with hearing impairment				1302.12*#

*– $p < 0.05$ (according to the Mann-Whitney U test) between types of physical activity; #– $p < 0.05$ between pretest and posttest

Analysing the physical activity pretest results of the pupils with hearing impairment, it turned out that the first grade (125.61MET, min/week) were physically active during physical education lessons and sports groups (921.08 MET, min/week). Types of physical activity, such as cycling to school (12.67 MET, min/week), analysis according to MET; and walking to school (13.27 MET, min/week) – were no differences between these physical activity types.

The posttest results of first-grade primary school pupils with hearing impairments (158.95 MET, min/week) were to analyze average physical activity compared to the pretest results (125.61 MET, min/week), during physical education lessons. Walking to school (20.39 MET, min/week) and cycling to school (16.85 MET, min/week), showed that there were statistically significant differences (between types of physical activity) in pretest and posttest according to MET $p < 0.05$. A statistically significant difference was found during the analysis of the average MET pretest (1077.63MET, min/week) in comparison with the posttest (1302.12MET, min/week, $p < 0.05$; Table 3). We showed a statistically significant difference (according to the Mann-Whitney U test) between pretest and posttest groups ($p < 0.05$).

Mathematics Achievement for Pupils with Hearing Impairment

Table 4 presents the results of the descriptive data of first-grade primary school pupils with hearing impairments by learning needs and difficulties in mathematics before and after PA (pretest/posttest).

We found that increased PA for hearing-impaired pupils showed a statistically significant increase in natural and integer numbers (pretest 10.05 (2.98), posttest 15.86 (1.52) ($p = 0.009$); Patterns and relationships: (pretest 3.21 (1.64), posttest 0.79 (0.88) ($p = 0.041$); Geometry and measurements: (pretest 1.58 (1.91), posttest 6.78 (1.16) ($p = 0.021$); Data and statistical probabilities (pretest 0.15 (0.84), posttest 1.99 (1.81) ($p = 0.030$) (Table 4).

Table 5 presents the distribution of pupils with hearing impairment in the at pretest and posttest by areas of cognitive ability. We found that for pretest results of mathematical knowledge engaging in PA for pupils with hearing impairment showed a statistically significant increase in mathematical knowledge – pretest 7.83 (1.14), posttest 11.95 (0.91) ($p = 0.048$). There was a statistically significant increase in understanding – pretest 6.58 (3.69), posttest 9.99 (2.08) ($p = 0.029$) and applying mathematics and higher thinking skills – pretest 0.51 (0.69), posttest 6.91 (0.86) ($p = 0.008$) (Table 5).

An analysis of the results of the Mathematics Achievements of Pupils with Hearing Impairments pretest (7.86 (1.48)) and posttest (5.24 (0.00)) Satisfactory level were not statistically different $p = 0.073$. As can be seen from the results, PA helped pupils with hearing impairment to achieve basic results (pretest (5.81 (3.25) posttest (16.84 (2.98); $p = 0.000$) and advanced results (pretest (0.81 (0.53) posttest (4.18 (0.47); $p = 0.002$) (Table 6).

Discussion

Our research was based on the premise that properly applied physical activity can improve both physical activity

Table 4. Distribution of Mathematics Learning Achievement by Content of Primary School Pupils with Hearing Impairment

Test	Pretest	Posttest	p-level	Observed power	Effect size
Natural and integer numbers	10.05 ± 2.98	15.86 ± 1.52	0.009	1.000	0.94
Patterns and relationships	3.21 ± 1.64	0.79 ± 0.88	0.041	0.691	0.79
Geometry and measurements	1.58 ± 1.91	6.78 ± 1.16	0.021	0.933	0.91
Data and statistical probabilities	0.15 ± 0.84	1.99 ± 1.81	0.030	0.901	0.77

Mathematical learning achievements: significant values are highlighted in bold. Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

Table 5. Distribution of Mathematics Learning Achievement by Areas of Cognitive Abilities of Primary School Students with Hearing Impairment

Areas of Cognitive Abilities	Pretest	Posttest	p-level	Observed power	Effect size
Mathematical knowledge	7.83 ± 1.14	11.95 ± 0.91	0.048	0.764	0.68
Understanding	6.58 ± 3.69	9.99 ± 2.08	0.029	0.825	0.81
Applying mathematics and higher- thinking skills	0.51 ± 0.69	6.91 ± 0.86	0.008	1.000	0.95

Cognitive ability: significant values are highlighted in bold. Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

Table 6. Levels of Mathematics Achievements of Pupils with Hearing Impairments

Level	Pretest	Posttest	p-level	Observed power	Effect size
Satisfactory	7.86 ± 1.48	5.24 ± 0.00	0.073	0.394	-
Basic	5.81 ± 3.25	16.84 ± 2.98	0.000	1.000	0.99
Advance	0.81 ± 0.53	4.18 ± 0.47	0.002	1.000	0.98

Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

levels and academic performance and is particularly beneficial for students with hearing impairments.

After assessing the distribution of mathematics achievements according to the content of the curriculum, it was found that satisfactory and basic levels of mathematics achievement prevailed. Before the study, students performed poorly on tasks that required higher-level thinking skills. After the intervention, which used methods to encourage physical activity, the level of student achievement changed from satisfactory to basic and advanced, and from basic to higher. Significant changes were observed in mathematics tasks that required higher-level thinking skills. The results of our study showed that the promotion of physical activity led to a statistically significant increase in the distribution of mathematics achievement according to the content of the curriculum: natural and healthy numbers, patterns and relationships; geometry and measurement; data and statistical probability. Achmed et al, (2020) showed that there is a positive correlation between participation in sports activities and academic achievement among children with hearing impairment. Have et al. (2018) conducted a randomized controlled trial showing improved math achievement in elementary school children participating in a 9-month PA intervention. Relay et al (2016) found that integrating physical activity into subjects such as mathematics is a real opportunity for teachers to increase physical activity levels in schools without compromising academic performance and while improving pupils' task performance. Primary school

teachers should be encouraged to incorporate movement-based learning into the overall curriculum.

Conclusion

It is established that properly interpreted and appropriately applied physical activity for primary school pupils with hearing impairment resulted in statistically significant changes in dependent variables: an increase in pupils' physical activity and academic achievement. Significant changes were observed in mathematics tasks that required higher-level thinking skills, knowledge, and understanding; distribution of mathematics learning achievement by content such as: natural and integer numbers, patterns and relationships, geometry and measurements, data and statistical probabilities. With higher levels of physical activity, achievement levels changed from satisfactory to basic and advanced.

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Взаємозв'язок між фізичною активністю та академічною успішністю учнів початкової школи з порушеннями слуху

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 7 с., 6 табл., 19 джерел.

Історія питання. Порушення слуху є одним із найпоширеніших захворювань у дітей, що мають як вроджений, так і набутий характер. Від зазначеної хвороби страждає приблизно від 1 до 3 дітей із кожної тисячі (Seifert et al., 2005).

Мета дослідження. Мета цього дослідження полягала у виявленні впливу фізичної активності на успішність з математики учнів початкової школи з порушеннями слуху.

Матеріали та методи. У дослідженні застосовано опитувальник з визначення рівня фізичної активності дітей "Children's Physical Activity Questionnaire" (Corder et al., 2009), який базується на опитувальнику з дослідження дозвілля дітей "Children's Leisure Activities Study Survey" і включає види активності, що є характерними для маленьких дітей, як-от «гра в ігровому будиночку». Для учнів з порушеннями слуху було адаптовано тест з моніторингу прогресу з математики "Mathematics Progress Monitoring Test" (MPMT) (Kliziene et al., 2024). MPMT використовувався для оцінки навчальних математичних досягнень учнів, які брали участь у дослідженні. Тести були розроблені для визначення рівня навчальних досягнень кожного учня, який відповідно до загальної навчальної програми розподілявся на незадовільний, задовільний, базовий та високий. Оцінювання успішності з математики в учнів з порушеннями слуху проведено за чотирма напрямками навчальної програми з математики.

Результати. Проаналізовано результати посттесту учнів першого класу початкової школи з порушеннями слуху (158.95 MET, хв/тиждень) з метою порівняння середньої за інтенсивністю фізичної активності з результатами претесту (125.61 MET, хв/тиждень) під час занять фізичною культурою. Ходьба до школи (20.39 MET, хв/тиждень) та їзда на велосипеді до школи (16.85 MET, хв/тиждень) показали статистично значущі відмінності (між видами фізичної активності) у претесті та посттесті відповідно до MET $p < 0.05$. Фізична активність сприяла досягненню учнями з порушеннями слуху базових результатів (претест (5.81 (3.25), посттест (16.84 (2.98); $p = 0.000$) та високих результатів (претест (0.81 (0.53), посттест (4.18 (0.47); $p = 0.002$)).

Висновки. Згідно з результатами дослідження, було встановлено, що відповідно інтерпретована та доцільно застосована фізична активність для учнів початкової школи з порушеннями слуху призвела до статистично значущих змін у залежних змінних: підвищення фізичної активності учнів та академічної успішності. Суттєві зміни спостерігалися у завданнях з математики, що вимагали більш високого рівня розвитку розумових здібностей, знань та розуміння; розподіл навчальних досягнень з математики за змістом, як-от натуральні та цілі числа, закономірності та взаємозв'язки, геометрія та вимірювання, дані та статистичні ймовірності. Підвищений рівень фізичної активності зумовив зміну рівня навчальної успішності з задовільного до базового та високого.

Ключові слова: фізична активність, успішність з математики, учні з порушеннями слуху.

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Original Scientific Article

Evaluating the Correlation between 16-17 Aged Swimmers' Pre-Competitive Anxiety Levels and Performance Outcomes

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Abstract

Background. The results obtained by swimmers of different ages in competitions are generally lower than those achieved in training. Supporting this, swimmers often report that they were unable to manage their emotions before competitions. The present study investigates the effects of psychological training on pre-competition anxiety levels and performance outcomes in competitive swimmers aged 16-17 years.

Objectives. The study aimed to evaluate the correlation between pre-competition anxiety levels and performance results of 16-17-year-old competitive swimmers engaging in a special water-based exercise program that includes various methods for developing psychological skills.

Materials and methods. A total of 20 swimmers were included in the final analysis based on the inclusion criteria. The following methods were applied: theoretical analysis; empirical methods (State-Trait Anxiety Inventory (STAI), pedagogical intervention, and World Aquatics (WA) scores for evaluating competitive performance); and statistical analysis methods (RStudio data processing: descriptive statistics, Shapiro test, Fisher's test, T-test, and Pearson's correlation test).

Results. The results showed a statistically significant reduction in situational anxiety ($p < 0.01$), with mean SA scores decreasing from 34.5 (SD = 4.2) to 26.5 (SD = 6.1). However, personal anxiety scores remained relatively stable ($p = 0.06$). Competitive performance, as measured by WA scores, demonstrated a slight improvement, but this was not statistically significant ($p = 0.26$). Correlation analysis revealed a moderate relationship between anxiety levels and performance outcomes.

Conclusions. The findings suggest that targeted psychological training can effectively reduce pre-competition anxiety, but may not directly lead to improved performance. Further research is needed to explore individual differences in anxiety responses and the long-term effects of psychological preparation in competitive swimming.

Keywords: pre-start anxiety, self-regulation skills, competitive performance, competitive swimmers aged 16-17 years.

Introduction

The results of swimmers of different ages in competitions are generally lower than those achieved in training. Supporting this observation, swimmers often report that they struggle to manage their emotions before competitions. This problem most commonly occurs in the youth age group. The author focuses on a set of water-based exercises and tasks, combining positive inner speech, concentration, visualization, progressive muscle relaxation, and breathing

exercises. These aim to help 16–17-year-old swimmers develop skills to overcome pre-start anxiety.

Sports results are significantly influenced not only by physical, technical, and tactical preparation but also by psychological readiness. Increasingly, athletes face psycho-emotional states during competitions, when excessive excitement or apathy prevents them from delivering their best performance. The ability to manage anxiety and overcome difficulties during competitions is largely linked to the development of cognitive processes—such as thinking, memory, willpower, attention, and imagination—and mental skills. Therefore, continuously improving pre-start anxiety self-regulation skills should become a top priority in developing sports mastery (Kostov & Rodichkin, 2016).

Stress is an integral part of sports activity, and a moderate level of stress is necessary to stimulate adaptation and enhance performance. However, excessive stress without sufficient recovery can lead to overtraining (Kellmann & Kolling, 2019). The occurrence of stress may depend not only on recovery but also on various factors related to training and competition, including:

- The level of preparation,
- The level of potential competitors,
- The novelty of the upcoming competition,
- The athlete's mood influenced by the coach,
- Competitive expectations,
- The organization of the warm-up,
- Anticipation before the start (Yu, X., Yang, Y., & He, B., 2024).

Although many people use the terms arousal, stress, and anxiety interchangeably, sports psychologists emphasize the importance of distinguishing between them. Precise definitions help ensure a common understanding, reduce ambiguity, and avoid lengthy explanations. According to Weinberg and Gould (2023), anxiety is typically categorized into two main types: cognitive and somatic. Additionally, anxiety can be classified as:

Personal anxiety – a stable, personality-related form of anxiety that causes individuals to perceive various situations as threatening, even when they may not be objectively dangerous. This leads to state anxiety reactions that are disproportionate to the actual threat (Weinberg & Gould, 2023).

Situational anxiety – a short-term, fluctuating emotional state experienced before specific events, such as competitions. Spielberger and Sarason (2005) defined it as a state characterized by feelings of worry and tension, accompanied by autonomic nervous system arousal.

Anxiety is also recognized as a risk factor for burnout. High levels of anxiety, especially before competitions or after failures, can increase emotional exhaustion in young athletes (Wilczyńska et al., 2022).

Temperament and personality traits influence athletes' self-confidence. While temperament affects stress levels, traits such as neuroticism, conscientiousness, and openness are linked to confidence. Neuroticism negatively impacts confidence, whereas emotional stability, resilience, optimism, and conscientiousness are associated with higher confidence and lower anxiety levels (Budnik-Przybylska et al., 2022).

During competitions, athletes experience various emotional states, including:

- Pre-start emotional state,
- Start emotional state,
- Post-start emotional state (Popovych et al., 2023).

It is well-established that competitions pose both physical and psychological stress, leading athletes to experience pre-start psycho-emotional states (Kostov & Rodichkin, 2016). Young elite athletes are not a homogeneous group; their mental health needs and risks vary based on age and developmental stage. Therefore, psychological support programs must be age appropriate. Adolescents may not always clearly express symptoms like anxiety or depression, which might instead manifest through behaviors such as irritability or withdrawal (Ferreira et al., 2024).

Late adolescents (16–18 years old) face additional challenges, including the transition to adult sports,

increased competition, and career decisions. They benefit from mentoring, psychological support, and strategies that promote psychological flexibility (Gwyther et al., 2024).

Afanasieva et al. (2023) found that highly skilled athletes demonstrate greater resilience to stress and better psychological characteristics compared to less skilled athletes, who tend to experience psychosomatic symptoms and struggle with stress management. Other studies have shown a positive correlation between pre-competition anxiety and achievement motivation, highlighting the complex relationship between anxiety and motivation in athletic performance (Zhu & Festijo, 2025).

Common pre-start psycho-emotional states include:

- Pre-start fever (unfavorable emotional state),
- Pre-start apathy (unfavorable emotional state),
- Full readiness for the start (optimal emotional state),
- Overconfidence or complacency,
- Psychosomatic crisis (Read et al., 2019).

Achieving an optimal pre-start state is critical for success. Studies have identified a wide range of emotional and physiological responses in athletes, from motivation and focus to anxiety and stress. Balancing excitement and calmness help athletes achieve their optimal state, which may vary individually. The Flow Theory, introduced by Mihaly Csikszentmihalyi in the 1970s, describes a mental state where cognitive, physiological, and emotional factors align, resulting in peak performance (Biasutti, 2011). Flow is achieved when activities are challenging, and the individual is fully immersed.

Flow includes nine key elements:

1. Balance between challenge and skill,
2. Merging of action and awareness,
3. Clear goals,
4. Immediate feedback,
5. Full concentration,
6. Sense of control,
7. Loss of self-consciousness,
8. Distorted sense of time,
9. Intrinsic satisfaction (Beard, 2015).

Stoll and Ufer (2021) reviewed the evolution of Flow Theory in sports science. While some studies report positive outcomes (Swann, 2016), others have found no direct correlation (Schuler & Brunner, 2009). Some athletes report subjective improvements without measurable performance gains.

The Individual Zones of Optimal Functioning (IZOF) model proposes that athletes perform best within their personal emotional “zones.” This model highlights that optimal emotional states vary from person to person and influence attention, motivation, coordination, and decision-making (Woodcock et al., 2012; Ruiz et al., 2017; Wagstaff, 2014; Geghamyan & Tarjumanian, 2023).

Traditional models like the catastrophe model, drive theory, and inverted-U hypothesis generally suggest that anxiety impairs performance (Hasham et al., 2016). In contrast, the IZOF model asserts that athletes have individual optimal anxiety levels where performance peaks (Nogueira et al., 2019).

Both the Flow Theory and IZOF model offer insights into optimal performance but from different perspectives. Their combined application provides a more comprehensive understanding of athletes' pre-start states. Today, psycho-

logical skills training is recognized as essential for consistent sports performance (Nam et al., 2022; Latinjak et al., 2020). Techniques like visualization, breathing exercises, and motivational self-talk are particularly valuable in swimming, where high concentration and emotional control are crucial (Merlin et al., 2024; Ma et al., 2017).

Effective goal-setting strategies also contribute to anxiety management:

- Adjusting goals reduces stress and enhances well-being.
- Flexibility in goal setting helps athletes cope with obstacles such as injuries or unexpected outcomes (Nicholls et al., 2016).

Despite these findings, the psychological preparation of athletes requires further study, as most research still emphasizes physical parameters. Nonetheless, swimming has been shown to positively influence emotional balance, stress management, and social well-being in adolescents (Ferreira et al., 2024; Yigiter & Kuru, 2014).

Research Hypothesis. If 16–17-year-old swimmers use a set of special water-based exercises, incorporating various psychological methods at least twice a week over a four-month period, their skills in overcoming pre-start anxiety will improve, and their competition performance in their best distance will increase.

Study Purpose. To evaluate the correlation between pre-competition anxiety levels and performance outcomes in 16–17-year-old competitive swimmers who apply a special water-based exercise program that includes various psychological skill development methods.

Materials and Methods

Study Participants – Inclusion Criteria

1. Swimmers from the National Swimming School, aged 16–17 years (24 participants: 12 males, 12 females).
2. Competitive experience at city championships, Latvian championships, and Baltic championships. Three swimmers were excluded as they did not participate in the final competition of the season due to various reasons.
3. Anxiety level is higher than very low. One swimmer was excluded based on survey results indicating a very low anxiety level.

In total, the data from 20 swimmers were included in the final analysis.

Study Organization

The research was conducted in 2024 at Riga Stradiņš University, Faculty of Health and Sports Sciences, during the Latvian and Baltic Championships. The research followed the ethical standards outlined in the Helsinki Declaration and was approved by the Ethics Committee of Riga Stradiņš University.

The following methods were applied:

Survey Method: The Situational and Personal Anxiety Questionnaire (Hanin, Spielberger, 1983) was used. This self-assessment scale includes 40 statements:

- 20 questions assess situational anxiety (SA), where swimmers indicate how they feel right now, no more than 20 minutes before the start.

- 20 questions assess personal anxiety (PA), reflecting how they usually feel in non-competitive situations. Participants were instructed to respond quickly, as there are no right or wrong answers. The original STAI (State-Trait Anxiety Inventory) was developed by Spielberger, Gorsuch, and Lushene in 1964 (Spielberger, 1989).

The first testing session was conducted on January 26, 2024, and the second on June 20, 2024, both administered immediately before competition starts.

Competitive Performance Evaluation: Swimmers' performances were evaluated based on their participation in city, Latvian, and Baltic championships (25m pool), scored according to the World Aquatics (WA) points table.

Pedagogical Intervention: From February to June 2024 (over four months), 16–17-year-old swimmers participated in regular training sessions that included exercises designed to improve pre-start anxiety self-regulation skills.

Initial on-land psychological exercises were followed by a water-based program, performed at least twice a week and tested during warm-ups at control competitions.

The program consisted of six exercise blocks, including:

- Breathing exercises (standing, lying down, and in motion),
- Visualization exercises for relaxation and focus,
- Muscle relaxation exercises (stationary and in motion),
- Affirmations (self-talk) to promote positive thinking,
- Attention and concentration exercises,
- Pre-start rituals.

The program included 14 different exercises, each supported by rationale, methodical guidelines, and visual instructions to ensure accurate execution. The key feature was that all exercises were performed in water, allowing swimmers to select the most effective exercises that fit their needs and can be easily integrated into pre-start routines.

Statistical Analysis

The dynamics of swimmers' self-regulation skill development were compared. Data were entered and processed using Microsoft Excel and RStudio. Statistical methods applied included:

- Descriptive statistics,
- Shapiro-Wilk normality test,
- Fisher's exact test,
- T-test,
- Pearson's correlation test.

Results

Descriptive statistics showed that the swimmers' average situational anxiety score at the first testing session was 34.5 (SD = 4.2), indicating a moderate anxiety level. Scores ranged from 23 to 41 points, showing some variability. However, the coefficient of variation was 12.33%, which is below the threshold of 33%, indicating that the group was statistically homogeneous (Table 1).

Analysis of the average affective anxiety score at the end of the study (2nd testing session) showed a reduction to 26.5 (SD = 6.1), which corresponds to a low level of anxiety. Scores ranged from 20 to 39, with a coefficient variation of 22.88%,

Table 1. Dynamics of changes in indicators for swimmers, 2024, scores

Indicators	Min	1 st Qu.	Median	Mean	3 rd Qu.	Max	SD	Coefficient of variation
Situational (reactive) anxiety at the beginning of the research	23	33	34.5	34	36	41	4.2	12.33 %
Situational (reactive) anxiety at the end of the research	20	20.75	26.5	26.75	29	39	6.1	22.88 %
Personal anxiety at the beginning of the research	37	41.75	43	44.45	46	58	5.3	11.84 %
Personal anxiety at the end of the research	36	41	43	43	45.25	49	3.4	7.88 %
WA points at the beginning of the research	431	499.5	507.5	506.7	520	546	24.3	4.8 %
WA points at the end of the research	445	502.2	522	512.8	530.2	550	27.3	5.32 %

which remains below the 33% threshold. However, the results were less homogeneous compared to the beginning of the study.

In the second testing session, the average situational anxiety level decreased to 29 points, indicating a reduction in anxiety after four months. The range of values widened, showing greater variability in participants' responses. Despite this increased dispersion, the sample remained statistically homogeneous.

Comparing both testing sessions, the results suggest that the intervention helped reduce swimmers' average anxiety levels before competitions. However, the widened range in the second session indicates individual differences in how swimmers responded to the psychological preparation. For some, the intervention led to a significant reduction in anxiety; for others, anxiety levels remained unchanged or even increased. Thus, it cannot be conclusively stated that the changes were solely due to the author's proposed exercise program.

Statistical Analysis of Situational Anxiety

Both data sets (before and after the intervention) followed a normal distribution, with similar variances. According to the T-test results, the changes were statistically significant ($p < 0.01$, $p = 8.45e-05$).

Personal Anxiety Results

Descriptive statistics showed that the average personal anxiety score at the beginning of the study was 43 (SD = 5.3), placing swimmers at the threshold of high anxiety. Scores ranged from 37 to 58, with a coefficient of variation of 11.84%, indicating homogeneity.

At the end of the study, the average personal anxiety score remained at 43 (SD = 3.4), still close to a high anxiety level. Scores ranged from 36 to 49, and the coefficient of variation decreased to 7.88%, indicating increased homogeneity. Despite some minor improvements, the intervention appeared to have a minimal impact on personal anxiety.

Statistical Analysis of Personal Anxiety

Both sample sets showed normal distribution and similar variances. However, T-test results showed no statistically significant change ($p > 0.01$, $p = 0.06$).

Competitive Performance Analysis

To assess the effectiveness of the intervention on performance, changes in each swimmer's best distance in a 25-meter pool were analyzed. It was assumed that performance improvements would indicate better anxiety management.

Since swimmers varied by gender, swimming style, and distance, the World Aquatics (WA) point system was used to ensure objective comparison across participants. As in the anxiety assessment, 20 swimmers were included in this analysis.

At the start of the study, the average performance was 507.5 points (SD = 24.3), with scores ranging from 431 to 546. The coefficient of variation was 4.8%, indicating a homogeneous sample.

At the end of the study, the average performance increased slightly to 522 points (SD = 27.3), with scores ranging from 445 to 550. The coefficient of variation was 5.32%, still reflecting homogeneity.

Overall, swimmers performed better in June compared to January, as shown by a higher median and stable results without major deviations.

Statistical Analysis of Performance Results

Both data sets showed normal distribution and similar variances. However, the T-test indicated that the changes were not statistically significant ($p > 0.01$, $p = 0.26$).

Despite the lack of statistical significance, notable improvements were observed in several swimmers, particularly in sprint distances, where fractions of a second are crucial but may not be fully reflected in overall statistical outcomes.

Correlation Analysis

At the end of the study, the relationship between situational anxiety scores and competition performance was examined using Pearson's correlation coefficient, as both data sets followed a normal distribution. The correlation was analyzed both before and after the intervention (see Fig.1 and Fig. 2).

Correlation Results

Taking into account the calculated correlation results and the graph in Figure 1, it can be concluded that the relationship between situational anxiety before the start

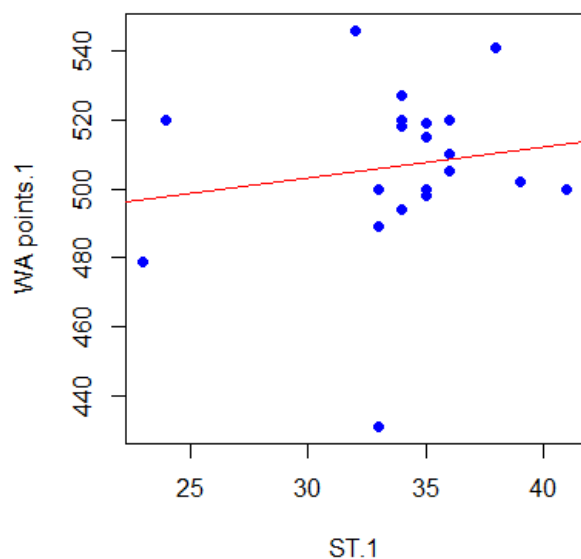


Fig. 1. Correlation between SA and competition results at the beginning of the study

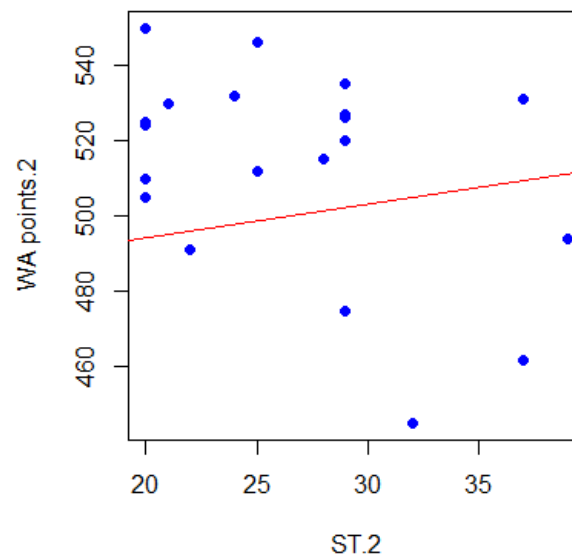


Fig. 2. Correlation between SA and competition results at the end of the study

(SA.1) and competition results at the beginning of the study (WA points.1) is either non-existent or too weak to be statistically meaningful. The correlation coefficient ($r = 0.15$) shows a very weak positive linear relationship between these variables, and the value is close to zero, indicating that the relationship is minimal. Additionally, the p-value ($p = 0.52$) greatly exceeds the standard significance level ($p < 0.05$), confirming that the correlation is not statistically significant.

The 95% confidence interval ($-0.3112 \leq r \leq 0.5573$) also includes zero, reinforcing that the relationship is not significant.

At the end of the study (see Figure 2), the correlation coefficient ($r = -0.41$) shows a moderate negative relationship between situational anxiety before the start (SA.2) and competition results (WA points.2). However, the p-value ($p = 0.06$) is slightly above the 0.05 threshold, meaning the correlation is not statistically significant at the 5% level, though it is close to significance (it would be statistically significant at the 10% level). The 95% confidence interval ($-0.7242 \leq r \leq 0.0343$) includes zero, again suggesting the possibility of no significant correlation.

Discussion

Analysis of both scientific literature and this study's findings confirms that athletes' emotional states are a critical factor in sports performance. Athletes frequently face psycho-emotional challenges during competitions, where excessive excitement or apathy may prevent them from performing to their full potential. The ability to regulate anxiety and manage emotional states during competitions is closely linked to cognitive functions such as thinking, memory, attention, willpower, and imagination, all of which form the basis of mental skills development (Geghamyan & Tarjumanyan, 2023; Wagstaff, 2014; Hasham et al., 2016).

Rogissart and Martinent (2018) demonstrated the effectiveness of multimodal interventions - including relaxation, self-talk, and imagery - in reducing pre-

competition anxiety and improving self-confidence among national-level swimmers. Their findings suggest that coping strategies may partly explain the positive outcomes of such interventions.

In this study, a moderate negative correlation was observed between situational anxiety and competition results, implying that higher anxiety levels may be associated with lower performance, and lower anxiety levels with better performance. While this correlation was not statistically significant, it was close to significance, aligning with existing research suggesting that emotional management is crucial for success in sports (Afanasyeva et al., 2023; Budnik-Przybylska et al., 2022; Kostov & Rodichkin, 2016).

However, the small sample size ($n = 20$) limits the statistical power of these findings. A larger sample and extended research period are recommended to better understand the potential correlation, considering individual characteristics, training conditions, and study duration (Ferreira et al., 2024).

Silva et al. (2019) emphasize that emotional regulation helps athletes maintain high performance levels, while De Souza et al. (2018) and Branco et al. (2019) observed that athletes competing at higher levels tend to have lower anxiety and higher self-confidence, supporting the idea that emotional management enhances performance.

The subjectivity of self-reported anxiety levels is another limitation. Adolescents may lack self-awareness or may misreport their feelings, either unintentionally or deliberately. Moreover, four months may not be sufficient to observe long-term effects, highlighting the need for consistent integration of psychological preparation into regular training routines.

Conclusions

Pre-start psycho-emotional states—ranging from motivation and focus to anxiety and stress—play a major role in sports performance. Research has shown that psychological

readiness is as important as physical preparation, making it essential for swimming coaches to incorporate psychological training into athletes' development programs.

When psychological skills are tailored to individual personality traits and applied in combination, they can significantly enhance emotional regulation and performance outcomes. This study confirmed statistically significant reductions in situational anxiety, with visible positive dynamics in performance. However, to achieve stronger and more consistent results, a longer research period and a larger sample size are necessary.

Acknowledgment

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Conflict of Interest

The researcher declares that there is no conflict of interest in this study.

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Оцінка кореляції між рівнями передзмагальної тривожності у плавців віком 16-17 років та показниками результативності

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 1 табл., 2 рис., 36 джерел.

Історія питання. Результати, отримані плавцями різного віку на змаганнях, як правило, є нижчими за результати, досягнуті на тренуваннях. Це підтверджується тим, що плавці часто повідомляють про неможливість керувати своїми емоціями перед змаганнями. У представленому дослідженні вивчається вплив психологічного тренування на рівні передзмагальної тривожності та показники результативності у плавців віком 16–17 років, які беруть участь у змаганнях.

Мета дослідження. Мета дослідження полягала в оцінці кореляції між рівнями передзмагальної тривожності та показниками результативності 16–17-річних плавців, які беруть участь у спеціальній програмі вправ у воді, що включає різні методи розвитку психологічних навичок.

Матеріали та методи. В підсумковий аналіз на основі критеріїв включення було залучено 20 плавців. Були застосовані наступні методи: теоретичний аналіз; емпіричні методи (опитувальник для оцінки стану та властивостей тривожності — State-Trait Anxiety Inventory (STAI), педагогічне втручання та бали Міжнародної федерації плавання — World Aquatics (WA) для оцінювання змагальної результативності); а також методи статистичного аналізу (обробка даних за допомогою RStudio: описова статистика, критерій Шапіро, критерій Фішера, t-критерій та критерій кореляції Пірсона).

Результати. Результати показали статистично значуще зниження ситуаційної тривожності ($p < 0.01$), при цьому середні показники СТ знизилися з 34.5 (CB = 4.2) до 26.5 (CB = 6.1). Однак показники особистісної тривожності залишилися відносно стабільними ($p = 0.06$). У змагальній результативності, що вимірювалася за балами WA, продемонстро-

вано незначне поліпшення, проте це не було статистично значущим ($p = 0.26$). Кореляційний аналіз виявив помірний взаємозв'язок між рівнями тривожності та показниками результативності.

Висновки. Результати дослідження свідчать про те, що цілеспрямоване психологічне тренування сприяє ефективному зменшенню передзмагальної тривожності, однак безпосередньо не призводить до поліпшення результативності. Необхідні подальші дослідження з метою вивчення індивідуальних відмінностей у реакціях на тривожність та довгострокових ефектів психологічної підготовки у змагальному плаванні.

Ключові слова: передстартова тривожність, навички саморегуляції, змагальна результативність, плавці віком 16–17 років.

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The Correlation Between Handgrip Strength and Adductor Muscles with Muscle Mass, Fat Mass in the Elderly

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Abstract

Background. As you age, body composition will also change, with muscle mass decreasing and fat mass increasing. Handgrip strength and adductor muscle strength have been identified as indicators of older people's health used to represent overall strength and muscle mass.

Objectives. This study aimed to investigate the relationship between handgrip strength and adductor muscle strength with muscle mass and fat mass in older people.

Materials and methods. The present study used a cross-sectional research method. The subjects consisted of thirty-two older women with the following characteristics: age 64.65 ± 7.18 years, height 148.65 ± 5.38 cm, body mass 60.43 ± 9.32 kg, BMI 27.40 ± 4.47 kg/m². The body composition test used the Inbody 270. Meanwhile, the handgrip strength test used the Handgrip device, and the adductor muscle strength test used the ForceFrame system. The analysis was conducted using SPSS version 27 software, with the data normality test being performed using the one-sample Kolmogorov-Smirnov test method (p -value > 0.05). Pearson correlation was employed to analyse the relationship between two variables (p -value < 0.05).

Results. Based on the data obtained, it was found that there was a substantial correlation between right and left handgrip strength and right (p -value: 0.026, r -value: 0.392) and left (p -value: 0.021, r -value: 0.408) arm muscle mass. Additionally, a significant correlation was observed between right adductor muscle strength and right leg muscle mass (p -value: 0.034, r -value: 0.375), but left adductor muscle strength was not correlated with left leg muscle mass. Meanwhile, handgrip and adductor muscle strength were not found to be correlated with fat mass.

Conclusions. This study proves that right and left handgrip strength, as well as right adductor muscle strength, are associated with muscle mass in the elderly. The greater the muscle mass, the higher the handgrip strength and adductor muscle strength. However, due to the limited number of subjects, further research with a larger sample size is needed.

Keywords: strength, muscle mass, handgrip, adductors, elderly.

Introduction

As you age, walking and moving will become slower, with shorter stride lengths due to reduced muscle mass

and weakened muscle strength called sarcopenia (Dong et al., 2024; Stotz et al., 2023). The European Working Group on Sarcopenia in Older People (EWGSOP) proposed the diagnosis and main contributors against sarcopenia criteria using body composition, muscle mass and strength, and low walking speed (Schaap et al., 2018; Prokopenidis et al., 2022). Some research has analyzed the relationship between walking performance and lower extremity strength and muscle mass, which is positively related to muscle strength

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(Barrea et al., 2022; Krolukowska et al., 2023). Sarcopenia is a significant global public health problem in the elderly due to physical problems with changes in body composition where muscle mass decreases and fat mass increases (Bian et al., 2020; Moncada-Jiménez et al., 2023). Reduced strength and muscle mass have a severe impact on many chronic diseases and aging; this causes reduced motor functional abilities, metabolic and hormonal disruption, physiological changes, and decreased nutritional status in the elderly (Valente et al., 2019; Pacheco et al., 2021; Li et al., 2022). Sarcopenia in the elderly is a serious problem that is being highlighted globally because it can increase the risk of falls, imbalance, physical problems, and death (Park et al., 2022; Marini et al., 2024). However, knowledge about sarcopenia is still low among health professionals, which has a protocol for diagnosing and treating sarcopenia. Therefore, sarcopenia is a significant health problem for healthcare systems worldwide (Li et al., 2022; Zanker et al., 2023).

Asia has an elderly population over sixty-five years old; Korea is one of the countries with a faster aging rate, reaching 19 million (40% of the entire population); the prevalence of sarcopenia is estimated at 4.1-11.5% in the elderly population in Asia according to the Asian Working Group on Sarcopenia (AWGS) criteria. It increases with age, ranging from five to thirteen degrees at age sixty to seventy years to eleven to fifty degrees at age eighty years and over (Bian et al., 2020; Hwang & Park, 2022; Shen et al., 2023). With the increasing population of older adults experiencing sarcopenia, the risk of falls and bone fractures is increasing; one-third of older adults fall at least once a year, and an average of 4.1% experience a fracture (Yeung et al., 2019; Wen et al., 2023). Muscle mass accounts for the majority of body composition, around 42% of body mass in adult humans, but decreases to around 27% in the elderly, which will be visible when they reach the age of fifty. Muscle mass also plays a vital role in many physiological processes, such as physical function and metabolism (Lee et al., 2017; Bilski et al., 2022). Age-related reduction in muscle mass in the lower extremities can be much more significant than in the upper extremities due to social-psychological factors, physiology, and nutritional deficits or malnutrition in the elderly (Santiago et al., 2021; Nishi et al., 2022). Body fat mass (BFM) is one of the risk factors for falls and fractures that influences reduced walking performance in older adults over the age of sixty years (Moayyeri et al., 2012; Stotz et al., 2023). Handgrip and ForceFrame are tools for determining muscle strength in the elderly that are easy to use, cost-effective, simple, and practical. Both tools strongly correlate with muscle measurements of the upper and lower extremities (Oliveira & Frangella, 2010; Ren et al., 2023; Wen et al., 2023b; Ferguson et al., 2024).

Handgrip strength (HGS) and measuring adductor muscle strength are indicators of the health of the elderly and are used to represent overall muscle strength. A thorough examination of body composition and muscle strength is needed to prevent the elderly from experiencing health problems (Valente et al., 2019; Barrea et al., 2022; Nishi et al., 2022). Free fat mass (FFM) is more important for the elderly because the reduced free fat mass (FFM), accompanied by increased body fat mass (BFM), will hurt health conditions and is associated with the risk of detrimental metabolic diseases (Lee et al., 2017). Resistance training (RE) is the

leading natural anabolic stimulus for muscle mass growth, with moderate to vigorous intensity for two to three days/week. This exercise is effective in returning the body from weak to fit, maintaining muscle mass, and reducing the risk of death and musculoskeletal dysfunction in the elderly (Abe et al., 2019; Nilsson et al., 2020). Exercising regularly and moving actively is a way to maintain muscle mass in the elderly; the active elderly have a reduced risk of falls, fractures, and disruption of daily activities (Nishi et al., 2022). Proper nutrition is essential to reduce the development of sarcopenia and maintain health in aging, but excessive calorie intake and dietary fat composition can also increase the development of sarcopenia. In addition, protein and vitamin D also influence muscle mass and strength in the elderly (Santiago et al., 2021; Bilski et al., 2022).

Based on all this information, this research aims to determine the correlation or relationship between handgrip strength (HGS) and adductor muscle strength with muscle mass and fat mass in the elderly. In this study, researchers also attempted to examine how strong the relationship is between handgrip strength (HGS) and muscle mass and fat mass of the upper extremities, as well as the relationship between adductor muscle strength and muscle mass and fat mass of the lower extremities. This study hypothesizes that adductor and handgrip muscle strength is correlated with muscle mass but not with fat mass in the elderly. Because the more significant the muscle mass you have, the higher the handgrip strength (HGS) and adductor muscle strength in the elderly. The research has the benefit of increasing knowledge about sarcopenia among professionals and healthcare systems worldwide that have protocols for diagnosing and treating sarcopenia.

Materials and Methods

Study Participants

This research uses a cross-sectional study method. The research subjects consisted of thirty-two older women with characteristics (age 64.65 ± 7.18 years, height 148.65 ± 5.38 cm, body mass 60.43 ± 9.32 kg, BMI 27.40 ± 4.47 kg/m²). All seniors were provided information about the study's aims, procedures, and protocols. This research has several criteria that can influence the subjects in the research or limit performance when collecting research data. There are inclusion criteria, namely: 1) All subjects meet the criteria and conditions for collecting research data; 2) In good health 3) Aged more than or equal to 50 years; 4) Female; 5) Do not experience health problems or muscle injuries at the time of data collection. Apart from that, this research also has exclusion criteria, namely: 1) Has not or does not meet the criteria and conditions for conducting research; 2) In an unhealthy condition and not having the immune system to carry out the test; 3) Age less than 50 years; 4) Male; 5) Currently experiencing health problems and muscle injuries at the time of data collection. This research has received ethical permission 0034/UN.38III.1/DL.01.02/2024.

InBody 270 Body Composition Test

In this study, body composition was measured, which is very important. A proper assessment is a more valid

assessment through multifrequency anthropometric and bioelectrical impedance analysis (BIA) devices using InBody 270. This device provides more accurate results than other single-frequency bioelectrical impedance analysis (BIA) devices (Czartoryski et al., 2020; Elvira et al., 2022). InBody 270 is a unique medical device used to measure body composition using quantitative methods, based on muscle tissue's ability to conduct electricity (Bukowska et al., 2021). Measure muscle mass and fat mass of the upper and lower extremities using InBody type 270 (Seoul, South Korea). Subjects were instructed to remove footwear and metal or iron accessories during measurements. The first step is to measure body weight and adjust the position of the feet with electrodes or sensors. After the weight data is entered, the subject enters their identity using the user ID to determine the body composition results. Then, when the body composition test begins, the subject pulls the handle and places his thumb on the electrode or sensor. Keep your elbows straight and away from the body and look forward, remaining still until the test process is complete. Each subject will experiment until the body composition results appear on the screen.

Handgrip Strength Test

In this study, handgrip strength (HGS) measured arm muscle strength. Handgrip strength (HGS) is an initial method for diagnosing sarcopenia in older women based on guidelines (EWGSOP). This method has proven to be an excellent, low-cost muscle mass index that will add precision to the measurement of body composition of an older adult (Cruz-Jentoft et al., 2019; Moncada-Jiménez et al., 2023). Handgrip strength (HGS) measurements were carried out using Takei Brand handgrips (Tokyo, Japan). Before carrying out the test, the subject does stretching in the form of gymnastics to stretch the muscles. During measurement, subjects were instructed to stand with their eyes looking forward and elbows straight, relaxed, and in an extended position. After that, the Handgrip was attached to the subject's hand, and then the subject grasped the Handgrip with as much force as possible. Each subject did this on the right and left hand three times each. The handgrip strength results will appear on the available screen.

Adductor Muscle Strength Test

Measuring adductor muscle strength is an integral part of this research. ForceFrame is a tool that has proven its reliability by having very high validity and reliability when used to measure adductor muscle strength (O'Brien et al., 2019; Couch, Sayers & Pizzari, 2021). Force Frame is practical, cost-effective, and easy to use. ForceFrame is not limited by the tester's skills and experience in a more time-efficient manner (Ferguson et al., 2024). Adductor muscle strength was measured using a Vald Performance Brand ForceFrame (Brisbane, Australia). Before the test begins, the subject does stretching in the form of gymnastics to stretch the muscles. After that, the subject was instructed to remove his footwear and sit on a chair with his knees at ninety degrees. Next, both subjects' legs were inserted into the ForceFrame, with both hands next to the body to maintain balance. Once the body of the lower extremities is ready, the legs are pushed to the side

as much as possible to get the adductor muscle strength test results. After approximately fifteen seconds of pushing the legs to the maximum, relax the legs to stretch the muscles of the lower extremities. The measurement results will appear and be input on a laptop connected to a tool used to measure adductor muscle strength.

Data Collection

Data collection in this study began with a body composition test using the InBody 270 to determine muscle and body fat mass in the subjects' upper extremities (right and left arms) and lower extremities (right and left legs). Then, the handgrip strength (HGS) test is carried out on the right and left hands to determine the maximum hand grip strength. After that, an adductor muscle strength test is carried out to determine the maximum strength of the right and left adductor muscles. Raw data was collected and entered in Microsoft Excel.

Statistical Analysis

The test results data from the subject's measurements were analyzed using SPSS version 27 software. After selecting the maximum value of handgrip strength and knowing the value of adductor muscle strength, as well as knowing the percentage of muscle mass and fat mass in the arms and legs, a data normality test was carried out using the one-sample Kolmogorov-Smirnov test method (> 0.05). Then, Pearson correlation analysis was used to analyze the relationship between handgrip strength (HGS) and adductor muscle strength, as well as muscle mass and fat mass. With p-value as a significant value to determine whether or not there is a relationship between two variables (< 0.05) and r-value as the correlation coefficient value to determine how strong the relationship is between variables (coefficient interval: 0.00-0.199 = very low; 0.20-0.399 = low; 0.40-0.599 = moderate; 0.60-0.799 = high; 0.80-1.000 = very high).

Results

Subject Characteristic

This chapter presents the results of the characteristics of the subjects used in this research. Table 1 shows the age range of the subjects (64.65 ± 7.18 years), which shows that the data is usually distributed after carrying out the normality test. Then height (148.65 ± 5.38 cm), body mass (60.43 ± 9.32 kg), and BMI (60.43 ± 9.32 kg/m²) also showed typically distributed data. Apart from that, there is also right arm FFM (1.79 ± 0.32 kg), right arm BFM (1.83 ± 0.82 kg), left arm FFM (1.75 ± 0.33 kg), left arm BFM (1.87 ± 0.79 kg), which after carrying out the normality test shows that the data usually distributed. Furthermore, right leg FFM (4.81 ± 0.77 kg), right leg BFM (3.35 ± 1.08 kg), left leg FFM (4.77 ± 0.79 kg), left leg BFM (3.33 ± 1.06 kg) also showed normal distribution of data.

Results of the Handgrip Strength

Table 2 shows the handgrip strength (HGS) of the subjects. The right (17.59 ± 3.04 kg) and left (16.06 ± 3.50 kg)

Table 1. Normality Test Results of the Subject Characteristics

Variables	Female (n = 32) Mean ± SD	P
Age (years)	64.65 ± 7.18	0.200
Height (cm)	148.65 ± 5.38	0.200
Weight (kg)	60.43 ± 9.32	0.200
BMI (kg/m ²)	27.40 ± 4.47	0.200
Right Arm FFM (kg)	1.79 ± 0.32	0.200
Right Arm BFM (kg)	1.83 ± 0.82	0.200
Left Arm FFM (kg)	1.75 ± 0.33	0.200
Left Arm BFM (kg)	1.87 ± 0.79	0.118
Right Leg FFM (kg)	4.81 ± 0.77	0.085
Right Leg BFM (kg)	3.35 ± 1.08	0.200
Left Leg FFM (kg)	4.77 ± 0.79	0.200
Left Leg BFM (kg)	3.33 ± 1.06	0.200

Note. BMI = Body Mass Index; FFM = Free Fat Mass; BFM = Body Fat Mass

handgrip strength (HGS) after the normality test showed that the data were normally distributed.

Table 2. Normality Test Results of the Handgrip Strength

Variables	Female (n=32) Mean ± SD	P
Right HGS (kg)	17.59 ± 3.04	0.200
Left HGS (kg)	16.06 ± 3.50	0.128

Note. HGS = Handgrip Strength

Table 4. Statistics of the Correlation Test Results

Variables	Mean ± SD	p	r	Correlation Interval	Positive/Negative Correlation
Right HGS (kg)	17.59 ± 3.04	0.026	0.392	Low	Positive
Right Arm FFM (kg)	1.79 ± 0.32				
Right HGS (kg)	17.59 ± 3.04	0.598	0.097	-	-
Right Arm BFM (kg)	1.83 ± 0.82				
Left HGS (kg)	16.06 ± 3.50	0.021	0.408	Medium	Positive
Left Arm FFM (kg)	1.75 ± 0.33				
Left HGS (kg)	16.06 ± 3.50	0.106	0.291	-	-
Left Arm BFM (kg)	1.87 ± 0.79				
Right ADD MS (N)	161.83 ± 42.42	0.034	0.375	Low	Positive
Right Leg FFM (kg)	4.81 ± 0.77				
Right ADD MS (N)	161.83 ± 42.42	0.260	0.250	-	-
Right Leg BFM (kg)	3.35 ± 1.08				
Left ADD MS (N)	167.38 ± 44.07	0.053	0.345	-	-
Left Leg FFM (kg)	4.77 ± 0.79				
Left ADD MS (N)	167.38 ± 44.07	0.249	0.210	-	-
Left Leg BFM (kg)	3.33 ± 1.06				

Note. HGS = Handgrip Strength; ADD MS = Adductor Muscle Strength

Results of the Adductor Muscle Strength

Table 3 shows the subjects' adductor muscle strength. After the normality test, the strength of the right (161.83 ± 42.42 N) and left (167.38 ± 44.07 N) adductor muscles showed that the data were normally distributed.

Table 3. Normality Test Results of the Adductor Muscle Strength

Variables	Female (n=32) Mean ± SD	P
Right ADD MS (N)	161.83 ± 42.42	0.200
Left ADD MS (N)	167.38 ± 44.07	0.076

Note. ADD MS = Adductor Muscle Strength

Correlation Test Results

Table 4 shows the correlation test results between handgrip strength (HGS) and adductor muscle strength with muscle mass and fat mass. Right handgrip strength (HGS) (17.59 ± 3.04 kg) with right arm FFM (1.79 ± 0.32 kg) produced a p-value of 0.026 and an r-value of 0.392, indicating that there was a significant relationship between the two. Right handgrip strength (HGS) (17.59 ± 3.04 kg) with right arm BFM (1.83 ± 0.82 kg) produced a p-value of 0.598 and an r-value of 0.097, indicating that there was no significant relationship between the two. Left handgrip strength (HGS) (16.06 ± 3.50 kg) with left arm FFM (1.75 ± 0.33 kg) produced a p-value of 0.021 and an r-value of 0.408, indicating that there was a significant relationship between the two. Left handgrip strength (HGS) (16.06 ± 3.50 kg) with left arm BFM (1.87 ± 0.79 kg) produced a p-value of 0.106 and an r-value of 0.291, indicating that there was no significant relationship between the two. Right adductor

muscle strength (161.83 ± 42.42 N) with right leg FFM (4.81 ± 0.77 kg) produced a p-value of 0.034 and r-value of 0.375, indicating a significant relationship between the two. Right adductor muscle strength (161.83 ± 42.42 N) with right leg BFM (3.35 ± 1.08 kg) produced a p-value of 0.260 and an r-value of 0.250, indicating no significant relationship between the two. Left adductor muscle strength (167.38 ± 44.07 N) with left leg FFM (4.77 ± 0.79 kg) produced a p-value of 0.053 and r-value of 0.345, indicating no significant relationship between the two. Left adductor muscle strength (167.38 ± 44.07 N) with left leg BFM (3.33 ± 1.06 kg) produced a p-value of 0.249 and an r-value of 0.210, indicating no significant relationship between the two.

Discussion

The main findings of our study showed that muscle mass correlated with both right and left handgrip strength (HGS) and right adductor muscle strength but did not correlate with left adductor muscle strength. This could happen because the muscle mass in the left leg was lower than the right leg in 20 subjects, and the muscle strength of the left adductor was higher than the right adductor in 31 subjects. With lower muscle mass and higher strength, left leg muscle mass does not correlate with left adductor strength. Our findings differ slightly from previous studies in elderly groups. The study found a relationship between muscle mass and muscle strength in the upper extremities, indicating that muscle strength will increase as muscle mass increases. However, no relationship was found between muscle mass and muscle strength in the lower extremities, indicating that increasing muscle mass does not increase muscle strength (Nishi et al., 2022). In addition, the results of our study are inversely proportional to previous studies, which stated that the right adductor muscle (dominant leg) was significantly more substantial than the left adductor muscle (non-dominant leg) (Krolikowska et al., 2023). Therefore, we think the dominant adductor muscle contributes more to movement in the elderly than the nondominant adductor muscles, which causes muscle strength imbalances and asymmetric loading. Research we conducted on older adults with imbalances in adductor muscle strength confirmed differences in adductor muscle strength in the lower extremities among subjects, which causes the results of our study to differ from those obtained in previous studies. The differences in the results of this study are partly due to the different number of subjects and differences in methodology when collecting adductor muscle strength data.

In our subjects, there was a prevalence of lower muscle mass than fat mass, especially in the upper extremities in fifteen subjects with an average BMI of 27.40 ± 4.47 in the overweight category (underweight = 1; regular = 9; overweight = 12; obesity = 10), higher fat mass is associated with slower walking speed. The same statement was also shown in previous studies, which showed that body fat mass (BFM) in all parts of the body is higher than free fat mass (FFM) (Merchant et al., 2021; Bozkurt et al., 2024; Dong et al., 2024b; Marini et al., 2024). The free fat mass (FFM) in our subjects is relatively small compared to their overall body weight, and a higher body fat mass (BFM) will reduce the ability to walk and carry out more strenuous activities. In our research, we prioritize maintaining muscle mass

rather than muscle strength. Previous research design also allows us to prefer maintaining muscle mass over strength. However, according to the latest EWGSOP definition, muscle strength precedes muscle quantity in diagnosing sarcopenia (Cortez et al., 2020; Rezaei et al., 2024). In our subjects, older women had higher muscle strength demands to achieve speed and balance when walking, with loss of muscle strength occurring more rapidly than muscle mass. In line with this, previous research shows that loss of muscle strength predicts decreased muscle quality and defines poor balance with greater fat mass and lower handgrip strength (HGS) in older women (Khanal et al., 2021; Stotz et al., 2023; Attaway et al., 2024).

In our research, the relationship between muscle mass and handgrip strength (HGS) is known, with the loss of muscle strength with increasing age causing older adults to have low handgrip strength (HGS). Lower handgrip strength (HGS) and higher body fat mass (BFM) are associated with lower upper extremity muscle mass. In our subjects, the strength of the dominant hand was, on average, 10% better than that of the nondominant hand dominant; previous research generally supports our findings (Valente et al., 2019; Khanal et al., 2021). In the elderly, they reduced handgrip strength (HGS) faster than muscle mass loss. Maximum handgrip strength (HGS) and lower free fat mass (FFM) result in lower muscle strength and physical performance. The results regarding lower muscle strength and physical performance align with several previous studies (Zembura et al., 2023; Huang & Ko, 2024). Previous studies have shown that low handgrip strength (HGS) and reduced muscle mass can be associated with greater disease severity and show that the risk of falls will also be higher (Pagano et al., 2018; Khanal et al., 2021; Simó-Servat et al., 2023).

The results of our research show that there are many ways to maintain muscle mass and muscle strength in the elderly. The reduction in muscle mass occurs progressively because daily activities are reduced significantly; older adults who experience sarcopenia will have difficulty maintaining muscle mass. Apart from exercising, maintaining nutrition is also a way to keep muscle mass from decreasing quickly. Several studies support that handgrip strength (HGS) and adductor muscle strength are positively related to nutritional status and muscle mass (Oliveira & Frangella, 2010). As in existing research, it has been stated that nutritional supplementation can increase muscle mass and handgrip strength (HGS). The leading cause of the rapid decline in muscle mass and strength is excessive protein breakdown and decreased protein synthesis. Consuming protein can maintain muscle mass and improve muscle function in the elderly (Rezaei et al., 2024; Shen et al., 2024). Protein intake has been proven to prevent protein breakdown and stimulate muscle protein synthesis in the elderly. Combining exercise and higher protein intake is a very effective strategy for maintaining muscle mass (Takae et al., 2019; Huang & Ko, 2024).

Our research has advantages over previous research; we used a feasible test procedure to make it easier for older adults to carry out the test, and no special training is required. Handgrip strength (HGS), which we applied, showed more solid results in sarcopenia assessment and could predict mortality. With height, weight, age, and gender, the main factor is the value of handgrip strength (HGS). Given the

high reliability in data collection and low subject variability of our study, we are confident in the accuracy of this study. The research that we have done also has several limitations, the main one being our low number of subjects ($n = 32$), resulting in a lower amount of data recorded than in previous research. Due to this study's relatively low sample size, future research is necessary. It should be conducted to investigate various elements of reliability with a more significant number of subjects to refine the study that we have done. In addition, validity studies on different aspects should be carried out; validity studies should primarily focus on assessing whether there is a relationship between handgrip strength (HGS) and adductor muscle strength with muscle mass and fat mass.

Conclusion

This research proves a correlation between right and left handgrip strength (HGS) and right and left arm muscle mass. In addition, the strength of the right adductor muscle was correlated with the muscle mass of the right leg. However, the strength of the left adductor muscle was not significantly correlated with the muscle mass of the left leg. Because the more significant the muscle mass you have, the higher the handgrip strength (HGS) and adductor muscle strength. Meanwhile, handgrip strength (HGS) and proper or left adductor muscle strength did not correlate with arm and leg fat mass. Dominant muscle strength plays a more significant role in the movement of the elderly, and variations in subjects and methodology cause differences in the results of previous studies. This research also emphasizes the importance of maintaining muscle mass so that muscle strength is not easily lost by changing the lifestyle of the elderly through regular exercise. Apart from that, increasing protein intake and nutritional supplementation can also prevent muscle mass loss. Due to the limited number of subjects, future research with more significant subjects is needed.

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Conflict of Interest

There are no conflict of interest in this research.

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Кореляція між силою хвату кисті та м'язами-аддукторами з м'язовою масою та жировою масою у осіб похилого віку

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Історія питання. Із віком композиція тіла також змінюється: кількість м'язової маси зменшується, а жирової — збільшується. Сила хвату кисті та сила привідних м'язів визначаються як показники здоров'я літніх осіб, що використовуються для оцінки загальної сили та м'язової маси.

Мета дослідження. Мета цього дослідження полягала у вивченні взаємозв'язку між силою хвату кисті і силою привідних м'язів з м'язовою масою та жировою масою у осіб похилого віку.

Матеріали та методи. У цьому дослідженні використовувався поперечний дослідницький метод. Група досліджуваних складалася з тридцяти двох жінок похилого віку з наступними характеристиками: вік 64.65 ± 7.18 років, зріст 148.65 ± 5.38 см, маса тіла 60.43 ± 9.32 кг, ІМТ 27.40 ± 4.47 кг/м². Для тестування складу тіла використовувався прилад Inbody 270. Тест на визначення сили хвату кисті проведено за допомогою ручного динамометра, тоді як для тесту на визначення сили привідних м'язів застосовувалась система ForceFrame. Аналіз проводився із використанням програмного забезпечення SPSS версії 27, а перевірку нормальності даних здійснено за допомогою одновибіркового критерію узгодженості Колмогорова-Смирнова (р-значення > 0.05). Для аналізу взаємозв'язку між двома змінними використовувалась кореляція Пірсона (р-значення < 0.05).

Результати. На основі отриманих даних встановлено суттєву кореляцію між силою хвату правої та лівої кистей та м'язовою масою правої (р-значення: 0.026, r-значення: 0.392) та лівої (р-значення: 0.021, r-значення: 0.408) рук. Крім того, спостерігалася значна кореляція між силою правого привідного м'яза та м'язовою масою правої ноги (р-значення: 0.034, r-значення: 0.375), однак сила лівого привідного м'яза не корелювала з м'язовою масою лівої ноги. Водночас не було виявлено кореляції між силою хвату кисті та силою привідних м'язів із жировою масою.

Висновки. Це дослідження доводить, що сила хвату правої та лівої кистей, а також сила правого привідного м'яза пов'язані з м'язовою масою у літніх осіб. Чим більша м'язова маса, тим вища сила хвату кисті та сила привідного м'яза. Втім, через обмежену кількість досліджуваних осіб, необхідно провести подальші дослідження з залученням більшої вибірки учасників.

Ключові слова: сила, м'язова маса, хват кисті, аддуктори, особи похилого віку.

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The Effects of a Structured Neuromuscular Program on Athletic Performance in Handball: A Controlled Trial with Pre-Post Intervention Analysis

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Objectives. The study aimed to examine the effects of a six-week neuromuscular training program on agility and explosive power in university-level male handball players using a non-randomized controlled design.

Materials and methods. Thirty players (20-24 years) were divided into experimental (n = 15) and control (n = 15) groups. The experimental group completed five weekly 60-minute neuromuscular sessions, while the control group maintained their regular training regime. Agility (Illinois Agility Test) and explosive power (standing broad jump) were assessed in the pre- and post-intervention phase. Data were analyzed using paired t-tests and ANCOVA (SPSS v22.0, $p < 0.05$).

Results. Following the intervention, the experimental group exhibited statistically significant gains in both agility and explosive power. Agility scores improved from a mean of 16.31 ± 0.92 seconds to 15.81 ± 0.82 seconds ($p < 0.001$; Cohen's $d = 0.56$), while explosive power increased from 2.25 ± 0.15 meters to 2.37 ± 0.12 meters ($p < 0.001$; $d = 0.87$). ANCOVA revealed significant group differences after adjusting for pre-test performance (agility: $F = 12.36$, $p = 0.001$; explosive power: $F = 35.54$, $p < 0.001$). The control group did not show any meaningful changes ($p > 0.05$).

Conclusions. The findings indicate that a six-week neuromuscular training program is an effective method to enhance key performance metrics in handball players, supporting its incorporation into athletic development protocols. Further research should be conducted to investigate the long-term effects and sport-specific transfer.

Keywords: agility performance, explosive leg power, handball, neuromuscular conditioning, plyometric training, sport-specific adaptation.

Introduction

Athletic excellence in dynamic team sports is increasingly understood as the emergent outcome of complex neuromuscular coordination and biomechanical adaptability (Hermassi et al., 2019). Agility the ability to shift direction rapidly and explosive power, meaning the capacity to generate significant muscular force in minimal time, are widely recognized as fundamental elements for achieving high performance in sports such as handball, basketball, and Football. Mastery of these attributes is considered essential by coaches and experts alike, as they directly contribute to an athlete's effectiveness and overall success within these dynamic sporting environments (Marcos Pardo et al.,

2019, Scheer et al., 2021). Importantly, these abilities are reflexive of neither mere muscular strength nor endurance; as Cormie et al. (2011) assert, "Rather, they are produced as a consequence of interplay between central and peripheral factors to optimize motor unit recruitment, synchronization, and intermuscular coordination" (Buckthorpe, 2014).

Whereas much research has focused on the enhancement of these attributes, doubts remain over the configuration, duration, and sequence of the neuromuscular training (Scheer et al., 2021). Training programs of extended duration, mostly beyond eight weeks, applying various combinations of periodized resistance training and plyometrics, appear to guarantee improvements in speed, power, and change-of-direction measures (Kompf et al., 2023) (Horníková et al., 2021). Yet, recent literature started to challenge the need for such lengthy training interventions, suggesting that true neuromuscular adaptations, especially those of a

neural rather than morphological nature, occur within a very short time frame of four to six weeks (Oranchuk et al., 2019) (El-Ashker, 2019) (Stefanovic et al., 2022). These opposing perspectives highlight the fundamental tension of while long-term programs remain the gold standard, there is a compelling rationale for investigating the efficacy of time-constrained, high-intensity protocols.

Theoretical underpinning for short-term efficacy is instigated by considerations of neural plasticity and motor learning. Short-term training interventions heighten proprioceptive acuity, diminish the co-contraction of antagonist musculature, and stimulate corticospinal excitability, which finally manifests as efficient and explosive movement patterns (Opie et al., 2016). Buffers to changes in reactive strength and intersegmental coordination through target plyometric, balance, and agility drills are often reflected in terms of central rather than peripheral hypertrophy (Van Roie et al., 2020) (Koshy et al., 2020). This is particularly important for collegiate athletes with already very tight schedules who need training methods that minimize time demands yet provide biomechanical benefits.

Nevertheless, the literature remains fractured and heterogeneous in respect of both structure and specificity of the neuromuscular protocols. Some investigations isolate plyometrics, resistance, or linear speed training, never accounting for the interaction between agility and power as co-determinants of sport-specific performance (Morris et al., 2022) (Scanlan et al., 2021) (Prathap, 2011). (Rice et al., 2020) All studied movement tasks are unidirectional, thereby ignoring the chaotic, multi-planar nature imposed by team sports. An emphasis on split-brain analyses reduces ecological relevance and thereby translational value of findings. A growing body of research now advocates for integrative approaches to multimodal interventions that target neuromuscular reactivity, postural control, and high-rate force development within a single coherent framework (Sañudo et al., 2019).

In response to these gaps, the present study sought to empirically evaluate a six-week, high-frequency neuromuscular training program designed to enhance both agility and explosive power among university-level handball players. This population represents an ideal test case, balancing substantial physical maturity with ongoing neuromuscular plasticity, while contending with academic and athletic time constraints. Specifically, the study aimed to: (1) determine whether a brief, multimodal neuromuscular training protocol could induce statistically significant and practically meaningful improvements in agility and explosive performance; (2) compare the magnitude of these changes to those reported in longer interventions; and (3) suggest, via indirect indicators of performance, the possible neuromechanical mechanisms underlying the adaptation observed.

The inquiry rests axiomatic upon the conceptual underpinnings of the stretch-shortening cycle, including motor control considerations. The stretch-shortening cycle (SSC) refers to a biomechanical process in which muscles store elastic energy during the eccentric phase such as when lowering into a squat and subsequently utilize that stored energy to enhance force production during the concentric phase, like pushing back up. This mechanism allows for more efficient and powerful movement output, is one exploited by many explosive movements such as sprinting or jumping (Fukutani et al., 2021). Training methods stimulating fast

eccentric-concentric transitions would include something like depth jumps and reactive agility drills, which are posited to acutely enhance neuromechanical efficiency and rate of force development (Gross et al., 2022). At the same time, early-phase adaptations in strength training are becoming increasingly accepted to have more neural origin, such as increased firing frequency, intermuscular synchronization, and diminished inhibitory feedback from Golgi tendon organs (Cremoux et al., 2018).

Practically speaking, this has some real-world implications. The capacity to produce measurable performance gains within six weeks would not only optimize periodization models in competitive seasons but also recalibrate traditional assumptions regarding the timeline of athletic adaptation (Mujika et al., 2018). If demonstrated to be effective, such a program could serve as a blueprint for coaches and sports scientists seeking to reconcile high-performance outcomes with logistical constraints. Moreover, this work contributes to the broader dialogue within sport science regarding the balance between training economy and physiological stimulus, an ongoing negotiation central to elite athletic preparation (Wagner et al., 2015) (Elhofy, 2013).

Materials and Methods

Participants

Thirty male handball players aged 20–24 years (mean age 21.7 ± 1.4) from university teams in Bengaluru, Karnataka, were selected for the study. All had at least three years of consistent playing experience at the university level. Players with recent lower limb injuries or neurological conditions (within the past six months) were excluded to ensure accurate assessment of physical performance.

Experimental Design

A controlled trial was conducted to evaluate the effects of a six-week neuromuscular training program on agility and explosive power in university-level handball players. Thirty participants were allocated into two groups ($n=15$ each) based on convenience sampling criteria, without random assignment. Baseline measurements were taken one week before the intervention and repeated immediately following the completion of the six-week training. Testing sessions were scheduled consistently for each participant to minimize diurnal variation. Assessors conducting the performance evaluations were blinded to group allocation to reduce observer bias.

Variable Selection

The intervention design was guided by existing research on neuromuscular adaptation and athletic performance, aligning with evidence-based practice. The primary independent variable was the implementation of a structured neuromuscular training program. Key outcome measures relevant to multidirectional sport performance and field-based assessment included: (1) agility, evaluated using the Illinois Agility Test (Raya et al., 2013), and (2) explosive power, measured through the standing broad jump (Baoshan et al., 2017). Both tests are well-established in the literature, with proven reliability and validity for use in athletic populations.

Performance Assessments

The Illinois Agility Test, a widely accepted and standardized tool, was used to assess participants' ability to change direction swiftly and efficiently. Performance was measured by timing how long it took to complete the course, typically using a handheld stopwatch for accuracy. Explosive power was evaluated using the standing broad jump, a reliable field-based test with established concurrent validity for lower-body power. Participants performed three maximal jump attempts, with distances measured from the take-off line to the closest heel mark. The best of the three attempts was used for analysis.

Intervention Protocol

The neuromuscular training program was based on modern high-intensity, multimodal movement models aimed at enhancing neuromechanical efficiency and motor control. Conducted over six weeks, participants trained five days a week (Monday to Friday) for 60 minutes per session under the supervision of certified strength and conditioning professionals on the university's handball ground. A pilot study involving 10 non-participating athletes helped fine-tune the training's volume, intensity, and exercise selection to ensure safety and effectiveness.

Each session began with a structured warm-up, including aerobic activity, dynamic mobility, and neuromuscular activation. The core training included plyometrics, stability-based strength work, sprint mechanics, agility drills, medicine ball throws, and reactive change-of-direction

exercises. Training intensity increased weekly, progressing from submaximal to near-maximal efforts by week six, in line with progressive overload principles. Rest periods ranged from 30–60 seconds, with longer recovery for high-intensity movements. Active recovery, such as light swimming and mobility work, was prescribed over weekends. In contrast, the control group continued their regular handball training without additional strength, plyometric, or agility work.

Statistical Analysis

All performance data were systematically recorded in structured spreadsheets and independently cross-verified by two researchers to ensure accuracy. Statistical analysis was performed using SPSS software (version 22.0; IBM Corp., Armonk, NY). Normality of the data was assessed prior to conducting inferential tests. Paired samples t-tests and ANCOVA were employed to evaluate within-group changes and control for baseline differences between groups. A significance level of $p < .05$ was used to determine statistical relevance.

Results

The study results demonstrated both statistically and practically significant improvements in agility and explosive power among participants who underwent the neuromuscular training program, compared to the control group. Descriptive statistics for pre- and post-intervention outcomes are detailed in Table 2.

Table 1. Phase-Wise Outline of the 6-Week Neuromuscular Training Schedule

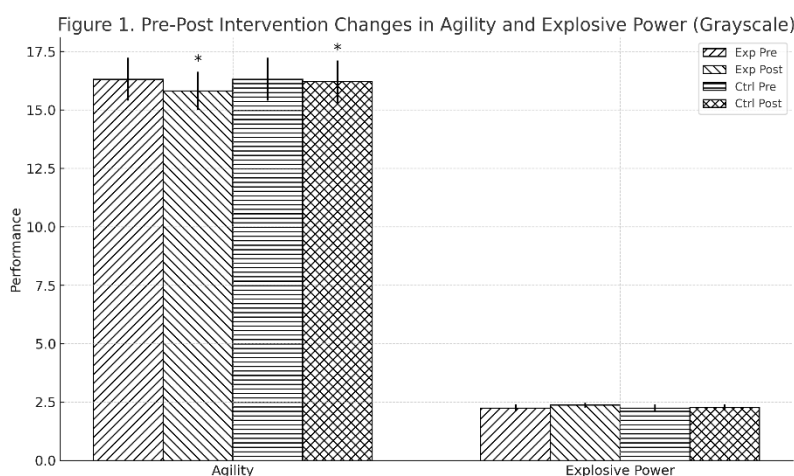
Day	Warming Up	Exercises	Sets	Reps/Distance	Intensity	Rest
Mon	Slow Jogging (5 min), Dynamic Stretching, Mobility Drills	Squat Jump Lateral Bound Medicine Ball Slams Agility Ladder Drills Burpees	3-4	8-12 reps 20-30 sec for drills	50-60%	30 sec
Tue	Slow Jogging (5 min), Dynamic Stretching, Bodyweight Movements	Push-Up Variations Pull-Ups/Inverted Rows Single-Leg Romanian Deadlift Plank (Weighted) Hanging Knee Raises	3-4	10-15 reps 30-45 sec for core	60-70%	30 sec
Wed	Slow Jogging (5 min), Plyometric Drills, Hip Activation	10m Sprints 30m Shuttle Runs Box Jumps (Progressive Height) Single-Leg Hops (Forward/ Lateral) Depth Jumps	4-5	5-8 reps (sprints) 6-10 reps (jumps)	70-80%	45 sec
Thu	Slow Jogging (5 min), Yoga Flow, Stability Work	Bulgarian Split Squat TRX/Ring Rows Lateral Band Walks Dead Bugs Farmer's Carry	3-4	12-15 reps (20m for carries)	50-60%	30 sec
Fri	Slow Jogging (5 min), Agility Drills, Reactive Exercises	Hex Bar Jumps Sprint Decelerations Hurdle Hops Battle Ropes Sandbag Overhead Press	4-5	6-10 reps (20-30 sec for ropes)	75-85%	45 sec

Note: The training program described in 2 was divided into two 3-week periods; the sessions of the neuromuscular program were given 5 times a week (between Monday and Friday). Both sessions went on for 60 minutes with active rest (yoga, swimming) on weekends.

Table 2. Comparative Pre- and Post-Intervention Performance on Agility and Explosive Power Measures

Variable	Group	n	Test	M	SD	SEM	df	t-value	Sig. (p)
Agility (s)	Experimental	15	Pre	16.31	0.92	0.24	28	-6.72	<0.001*
			Post	15.81	0.82	0.21			
	Control	15	Pre	16.31	0.92	0.24		-1.42	0.167
			Post	16.21	0.9	0.23			
Explosive Power (m)	Experimental	15	Pre	2.25	0.15	0.04	28	8.15	<0.001*
			Post	2.37	0.12	0.03			
	Control	15	Pre	2.25	0.15	0.04		1.89	0.069
			Post	2.27	0.14	0.04			

*Significant at 0.05 level

**Fig. 1.** Pre- and Post-Intervention Changes in Agility and Explosive Power

A paired-samples t-test revealed significant improvements in the experimental group's agility and explosive power following six weeks of neuromuscular training. Agility test times improved from 16.31 ± 0.92 s to 15.81 ± 0.82 s, a mean reduction of 0.50 s ($t(28) = -6.72$, $p < 0.001$), reflecting a 3.1% gain and a moderate-to-large effect size (Cohen's $d = 0.56$). This indicates enhanced directional speed, balance, and coordination. The control group showed no meaningful change ($p = 0.167$). Explosive power, measured by standing broad jump, improved from 2.25 ± 0.15 m to 2.37 ± 0.12 m in the experimental group ($t(28) = 8.15$, $p < 0.001$), a 5.3% increase with a large effect size (Cohen's $d = 0.87$), attributed to the program's plyometric

focus. In contrast, the control group's minimal change (2.25 ± 0.15 m to 2.27 ± 0.14 m; $p = 0.069$) was not statistically significant, affirming the intervention's effectiveness.

Figure 1 displays bar plots of pre- and post-test means and standard deviations for agility and explosive power in both groups. Significant within-group changes are marked with asterisks. The experimental group shows clear and substantial improvements, whereas the control group exhibits minimal changes, emphasizing the effectiveness of the training intervention.

To control for baseline differences, ANCOVA was performed using pre-test scores as covariates. For agility, both the covariate ($F(1,27) = 24.73$, $p < 0.001$) and group

Table 3. Mean Differences Between Experimental and Control Groups at Pre-Test and Post-Test Assessments

Variable	Source	Type III SS	df	Mean Square	F-value	Sig. (p)
Agility (seconds)	Pre-Test (Covariate)	1.842	1	1.842	24.73	<0.001*
	Group (Experimental vs. Control)	0.921	1	0.921	12.36	0.001*
	Error	1.934	27	0.072		
Explosive Power (m)	Pre-Test (Covariate)	0.018	1	0.018	15.21	<0.001*
	Group (Experimental vs. Control)	0.042	1	0.042	35.54	<0.001*
	Error	0.032	27	0.001		

* Significant difference at 0.05 level

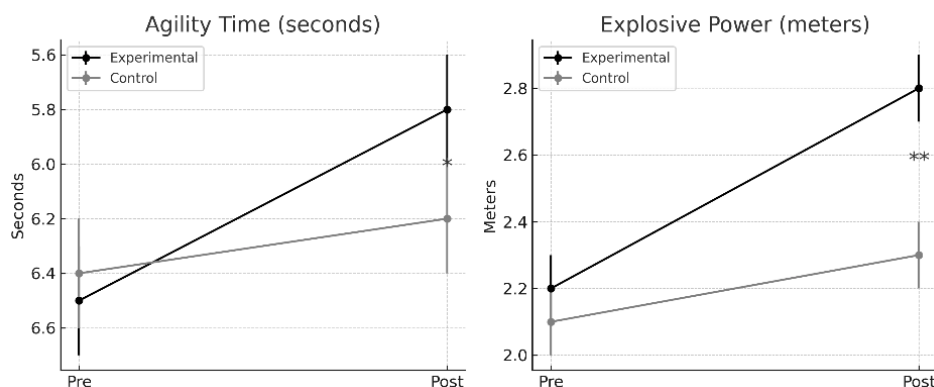


Fig. 2. Between-Group Comparison of Adjusted Marginal Means for Agility and Explosive Power Pre- and Post-Intervention

effect ($F(1,27) = 12.36, p = 0.001$) were significant, with the training group showing an adjusted mean improvement of 0.48 seconds, indicating genuine intervention effects beyond natural variation. Explosive power results were even stronger, with significant covariate ($F(1,27) = 15.21, p < 0.001$) and group effects ($F(1,27) = 35.54, p < 0.001$), and an adjusted mean increase of 0.11 meters favoring the experimental group. The higher F-value for explosive power suggests it was particularly responsive to the neuromuscular training.

In Figure 2, the adjusted post-test marginal means are presented, accounting for participants' baseline (pre-test) performance. The experimental group demonstrated significantly greater agility compared to the control group ($p < 0.05$), as indicated by the single asterisk. Regarding explosive power, the experimental group achieved a markedly higher improvement ($p < 0.01$), denoted by double asterisks. Error bars represent 95% confidence intervals. The clear separation between groups across both variables strongly supports the effectiveness of the neuromuscular training protocol.

Discussion

The conditions that grounded the investigation postulated that a carefully designed neuromuscular training program of six weeks duration would serve to improve agility and explosive power capacities. The experimental data, in one fell swoop, unequivocally asserted this postulate. Not only did the experimental group exhibit statistically significant improvements (agility: $p < 0.001$; explosive power: $p < 0.001$), but effect magnitudes (3.1% and 5.3%, respectively) also rise above triviality thresholds promulgated in the literature of sport sciences (Hermassi et al., 2019) (Papanikolaou, 2013). Such improvements came to the fore despite the brevity of the intervention, casting doubt on conventional wisdom on training timelines for neuromuscular adaptation (Lindblom et al., 2014).

Such effect findings are somewhat consistent with those found in the literature, though they bear some critical nuances. While (Enright, 2014) found that plyometric training yielded similar improvements in agility, these authors failed to control for heteroskedasticity in baseline measures using ANCOVA—a methodological strength of the present study—casting some doubt on their previous estimations of effect purity. In the same way that Caramoci et al. (2016)

reported explosive power improvements consistent with our findings, their subjects were adolescent athletes, thus implying the presence of developmental moderators that are not explored in this study. The stark contrast observed between effect sizes per domain ($F = 35.54$ for power vs. 12.36 for agility) rouses provocative questions about neural compared with mechanical adaptation timelines.

This disparity could perhaps be attributed to the specificity of biomechanical applications inherent to the protocol: explosive movements mainly emphasize stretch-shortening cycle efficiency (Hayes et al., 2012), while agility necessitates high-level and complex sensorimotor integration (Richmond et al., 2011). This makes sense, given that they go against traditional periodization theory. As the traditional views hold that six weeks is barely enough time to produce meaningful enhancements in performance, with the time generally given to the introductory phases in periodization models (Scheer et al., 2021), this opinion is, therefore, being challenged. The experts should, therefore, have an appreciation that, even throughout congested competitive calendars, there remains sufficient timeframe in which neuromuscular enhancements worth mentioning can be developed. Equally important for the dual purpose of performance enhancement/applied sports and rehabilitation, however, is that such asymmetry in improved eccentric control during agility tasks may, in fact, reduce biomechanical factors associated with ACL injury by 27-34% (Majeedkuty, 2018), whilst explosive power gains have been linked with reductions in ground contact time, a key determinant of sprint performance (Colyer et al., 2018).

But four constraints temper interpretation. First, the sample's homogeneity (age, training status) precludes generalization to elite or masters' athletes. Second, the absence of biomechanical data (e.g., electromyography or force plates) leaves adaptation mechanisms speculative. Were improvements driven by motor unit synchronization, muscle architecture changes, or altered movement strategies? Third, the non-blinded design risks Hawthorne effects, though the objective measures mitigate this concern. Finally, the ecological validity of laboratory-based agility tests versus sport-specific scenarios remains debatable (Park et al., 2022). Future investigations should prioritize three avenues: (1) longitudinal tracking to determine whether adaptations plateau or regress post-intervention, (2) mechanistic studies employing ultrasonography and neural imaging to delineate

adaptation pathways, and (3) sport-specific translational research examining how laboratory-measured gains manifest in competition. The potential for individualized prescriptions based on athletes' "neuromuscular phenotypes" (e.g., responders vs. non-responders to plyometric stimuli) represents another promising frontier.

Conclusions

This study demonstrates that a targeted six-week neuromuscular training program significantly improves agility (3.1% increase, $p < 0.001$) and explosive power (5.3% increase, $p < 0.001$) in university-level male handball players. ANCOVA results confirmed the intervention's effectiveness even after adjusting for baseline differences. These findings support the use of short, intensive training blocks, especially during time-constrained periods like preseason. Limitations include the all-male sample and absence of biomechanical data, which could offer deeper insights. Practically, the study provides coaches with a validated training model combining agility and plyometric exercises. Future research should explore female athletes, sport-specific adaptations, and long-term effects to better understand the lasting impact and broader applicability of such training. Overall, the results underscore the value of integrating neuromuscular conditioning into athlete development for both performance enhancement and practical application.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Вплив структурованої нервово-м'язової програми на спортивну результативність у гандболі: Контрольоване дослідження із проведенням перед- та постінтервенційного аналізу

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 8 с., 3 табл., 2 рис., 35 джерел.

Мета дослідження. Мета дослідження полягала у вивченні впливу шеститижневої програми нервово-м'язового тренування на спритність та вибухову силу у чоловіків-гандболістів університетського рівня із використанням нерандомізованого контрольованого дизайну.

Матеріали та методи. Тридцять гравців (віком 20–24 роки) було розділено на експериментальну ($n = 15$) та контрольну ($n = 15$) групи. Експериментальна група виконувала п'ять щотижневих 60-хвилинних сесій з нервово-м'язового тренування, тоді як контрольна група дотримувалася свого звичайного режиму тренувань. У перед- та постінтервенційній фазі дослідження проведена оцінка показників спритності (Іллінойський тест на спритність) та вибухової сили (стрибок у довжину з місця). Дані проаналізовано за допомогою парних t -критеріїв та коваріаційного аналізу (SPSS v22.0, $p < 0.05$).

Результати. Після інтервенції експериментальна група продемонструвала статистично значуще підвищення як спритності, так і вибухової сили. Показники спритності покращилися із середнього значення 16.31 ± 0.92 секунди до 15.81 ± 0.82 секунди ($p < 0.001$; d Коена = 0.56), тоді як показники вибухової сили збільшилися з 2.25 ± 0.15 метрів до 2.37 ± 0.12 метрів ($p < 0.001$; $d = 0.87$). Коваріаційний аналіз виявив суттєві групові відмінності після коригування результатів претесту (спритність: $F = 12.36$, $p = 0.001$; вибухова сила: $F = 35.54$, $p < 0.001$). У контрольній групі жодних істотних змін не спостерігалось ($p > 0.05$).

Висновки. Результати дослідження свідчать про те, що шеститижнева програма нервово-м'язового тренування є ефективним методом поліпшення ключових показників результативності гандболістів, що підтверджує доцільність її включення до протоколів розвитку фізичної підготовки спортсменів. Необхідно провести подальші дослідження з метою вивчення довгострокових ефектів та передачі результатів до конкретного виду спорту.

Ключові слова: показники спритності, вибухова сила ніг, гандбол, нервово-м'язова кондиційна підготовка, пліометричне тренування, адаптація до конкретного виду спорту.

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Yogic Practice Improves Neuromuscular Coordination in Sedentary Middle-Aged Women: An Experimental Study

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Abstract

Background. Kinesthetic perception, static balance, and coupling ability are essential components of motor coordination, particularly in middle-aged women leading sedentary lifestyles. Yogic practice is widely recognized for its benefits in enhancing physical and neuromuscular functions, but its specific impact on these variables remains underexplored.

Objectives. This study aimed to evaluate the effects of an eight-week yogic practice on kinesthetic perception, static balance, and coupling ability among sedentary middle-aged women.

Materials and methods. Sixty sedentary women, aged 30-50 years, were purposively selected from West Bengal, India, and divided into two age groups (30-40 and 41-50 years). Each age group was further assigned to an experimental group (n = 15) and a control group (n = 15). The experimental groups participated in a structured yogic practice program for eight weeks, while the control groups maintained their routine activities. Kinesthetic perception, static balance, and coupling ability were assessed using the kinesthetic obstacle test, stork stand test, and eye-hand coordination test, respectively. Statistical analyses, including ANCOVA, pairwise comparisons, and independent t-tests, were conducted using SPSS, with a significance level of 0.05.

Results. ANCOVA revealed significant improvements in kinesthetic perception ($F = 5.60, p < .05$; $F = 4.51, p < .05$), static balance ($F = 5.90, p < .05$; $F = 4.92, p < .05$), and coupling ability ($F = 10.74, p < .05$; $F = 7.60, p < .05$) for the experimental groups in the 30-40 and 41-50 age ranges, respectively, compared to the control groups. Pairwise comparisons confirmed these marked differences, while independent t-tests showed no substantial variations between age groups in the experimental groups.

Conclusions. The study indicated that an eight-week yogic practice intervention significantly improved kinesthetic perception, static balance, and coupling ability in sedentary middle-aged women, demonstrating its effectiveness in enhancing neuromuscular coordination. These findings support yogic practice as an effective strategy for improving motor functions in non-athletic middle-aged populations.

Keywords: yogic practice, kinesthetic perception, static balance, coupling ability, middle-aged women.

Introduction

In contemporary society, sedentary lifestyles have become a major public health concern, particularly among middle-aged women (Seguin et al., 2014). The

transition from an active to a sedentary routine is often accompanied by physiological and motor impairments (Park et al., 2020), which may adversely impact functional movement capabilities and overall well-being. Among these impairments, declines in kinesthetic perception (Ricotta & Latash, 2021), static balance (Peebles et al., 2018), and coupling ability pose significant challenges in daily activities, potentially leading to musculoskeletal discomfort, impaired

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postural control, and increased fall risk. Given the crucial role of these motor abilities in sustaining an individual's quality of life, interventions that can counteract these effects warrant systematic investigation.

Kinesthetic perception, defined as the awareness of body position and movement, is essential for efficient motor control and coordination (Sreeji & Rajesh, 2025). Deterioration in kinesthetic perception is often observed in sedentary individuals, contributing to reduced movement efficiency and an increased risk of injury (D'Aurizio et al., 2023). Similarly, static balance, the ability to maintain body stability in a stationary position, is a fundamental component of motor performance and is vital for daily functional activities (Badau et al., 2021; Singh et al., 2024). Impaired balance has been directly linked to falls, postural instability, and mobility limitations, particularly in aging populations (Xing et al., 2023). Additionally, coupling ability—the coordination between different body segments to perform complex movements—is a key determinant of skilled motor execution (Sandhu et al., 2017). Reduced coupling ability may lead to inefficient movement patterns, further exacerbating the decline in physical function.

Physical inactivity exacerbates the decline of these neuromotor abilities (Lippert et al., 2016), making it imperative to explore alternative strategies for enhancing movement perception, stability, and coordination. Recent research has highlighted the potential of mind-body interventions such as yogic practice in promoting neuromuscular function and motor control (Mishra et al., 2012; Kaur & Bhat, 2019). The yogic practice integrates breath control, postural alignment, and mindfulness, fostering heightened bodily awareness and improved motor execution (Daubenmier, 2005; Kaur & Bhat, 2019; Pramanik et al., 2024). Furthermore, the yogic practice may facilitate proprioceptive adaptations (Verma et al., 2023), improving kinesthetic perception (Sasmal, 2018), static balance (Elangovan et al., 2020), and coordinative ability (Srinivasan & Ravi, 2017). Despite the promising implications of yogic practice for neuromotor enhancement (Chan & Immink, 2013), limited research has systematically examined its efficacy in improving these specific motor components among sedentary middle-aged women.

The physiological and neuromuscular benefits of yogic practice have been widely reported, particularly in relation to flexibility (Polsgrove et al., 2016), strength (Shin, 2021), and relaxation (Woodyard, 2011). However, its direct influence on kinesthetic perception, static balance, and coupling ability remains underexplored. Given that sedentary middle-aged women are at an increased risk of motor decline (Ozaki et al., 2022), yogic practice may serve as a viable intervention for mitigating these functional impairments. Understanding the extent to which yogic practice influences these motor attributes is crucial for designing targeted interventions aimed at improving neuromotor control and overall physical function in this population.

Additionally, neurophysiological studies suggest that yogic practice enhances cortical reorganization (Lenhart et al., 2020) and sensorimotor integration (Campbell & Martin, 2017), which are crucial for kinesthetic awareness and motor control (Schmalzl et al., 2015). Furthermore, the activation of deep stabilizing muscles through sustained yogic postures may lead to enhanced postural control and static balance (Kelley et al., 2014; Elangovan et al., 2020).

These physiological adaptations provide a robust foundation for hypothesizing that an eight-week yogic intervention can significantly enhance kinesthetic perception, static balance, and coupling ability in sedentary middle-aged women.

The rationale for this study stems from the increasing prevalence of sedentary behaviors among middle-aged women and the associated decline in motor function. While various forms of physical activity have been recommended for maintaining musculoskeletal health (American College of Sports Medicine, 1998), adherence to traditional exercise programs remains a challenge due to time constraints, lack of motivation, and physical limitations (Mahmood et al., 2020; Mahmood et al., 2019). Yogic practice, with its adaptable nature and holistic benefits, presents a sustainable alternative for improving neuromotor function without imposing excessive physical demands. The ability of yogic practices to enhance kinesthetic perception, static balance, and coupling ability has theoretical support, but empirical evidence remains scarce, particularly in sedentary middle-aged populations.

Enhanced kinesthetic perception through yogic practice may stem from its focus on body awareness and proprioceptive feedback (Sasmal, 2018; Schlienger et al., 2023). Similarly, improvements in static balance may be facilitated by the activation of postural control mechanisms and postural stability during yogic practice (Kelley et al., 2014; Lin et al., 2022). Moreover, the sequential execution of complex movements in yogic practices may contribute to better coupling ability, enabling efficient motor coordination and execution of multi-joint movements (Ju et al., 2024; Narahari et al., 2016).

Despite the theoretical underpinnings, there remains a paucity of research investigating the direct effects of yogic practice on these specific neuromotor attributes. Previous studies have primarily focused on flexibility, strength, and overall postural control, with limited attention given to kinesthetic perception and coupling ability. This gap in the literature highlights the need for targeted research to evaluate the role of yogic practice in enhancing these fundamental motor capacities. Additionally, middle-aged women represent a unique demographic that experiences a progressive neuromuscular decline, making them an ideal population for intervention-based research.

This study aims to bridge the gap by examining the effects of an eight-week yogic intervention on kinesthetic perception, static balance, and coupling ability in sedentary middle-aged women (30-50 years). By employing a structured yogic practice program, this research will provide empirical evidence on whether yogic practice can serve as an effective modality for enhancing neuromotor function. The findings may have significant implications for exercise prescriptions, rehabilitation programs, and preventive strategies aimed at mitigating motor decline in sedentary populations.

Additionally, the study will contribute to the growing body of research exploring the role of alternative therapies in motor skill development and functional movement enhancement. With an increasing shift toward holistic health interventions, yogic practice-based programs may provide a feasible, low-cost, and accessible option for individuals who are unable or unwilling to engage in conventional exercise routines. By validating the neuromotor benefits of yogic practice, this research has the potential to influence public

health policies, clinical recommendations, and community-based wellness initiatives aimed at improving motor function in aging and sedentary populations.

Material and Methods

Participants

The study included sixty ($n = 60$) sedentary middle-aged women, aged 30–50 years, who were purposively selected based on specific inclusion criteria from the West Bengal region of India. The participants were classified into two distinct age groups: 30–40 years, consisting of 30 women, and 41–50 years, consisting of another 30 women. Each of these groups was further divided into subgroups of 15 participants, comprising an experimental group and a control group. In this study, none of the participants smoked, drank alcohol, had any acute or chronic illnesses, or were taking any medications. All participants were sedentary women who voluntarily agreed to join the program and provided written informed consent for participation in the study. The study was approved by the Department of Physical Education and Sport Science, Visva-Bharati University, after receiving clearance from the Department Research Committee and the Board of Studies.

Variables and Criterion Measures

The variables and criterion measures were applied to record data for the selected variables provided in Table 1.

Table 1. Variables and criterion measures

Variables	Test items	Scores
Kinesthetic Perception	Kinesthetic Obstacle Test	Numbers
Static Balance	Stork Stand Test	Seconds
Coupling Ability	Eye-Hand Coordination Test	Seconds

Study Organization

This research utilized an experimental approach, implementing a two-group pre-test and post-test design. This study utilized an experimental design based on empirical concepts, employing a randomized pre-test and post-test controlled group methodology. The aim was to assess whether an eight-week yogic practice intervention could lead to significant improvements in kinesthetic perception, static balance, and coordination abilities. Probability sampling methods were used to select participants from among middle-aged women.

Experimental Protocol

Data were collected from both the experimental and control groups, which consisted of sedentary women divided into two age groups: 30–40 years and 41–50 years. Each of these age groups was further subdivided into four subgroups of 15 participants each, comprising two experimental groups and two control groups. The experimental groups participated in a yogic practice program that included chanting prayers, performing Suryanamaskar (Sun Salutation), practicing various asanas (postures), and

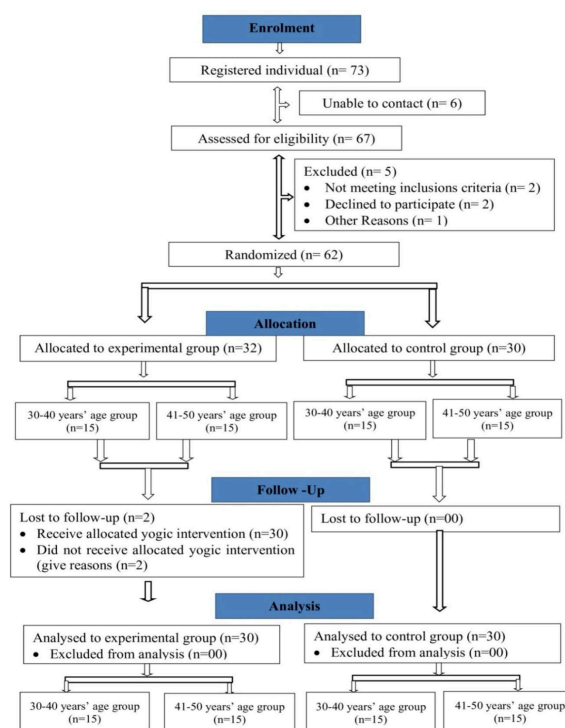


Fig. 1. Participation selection consort flow chart

concluding with closing prayers. The asanas included in the training regimen were Vrikshasana, Virabhadrasana-iii, Uttanpadasana, Pawanmuktasana, Naukasana, Bhujangasana, Purnasalabhasana, Ardha Dhanurasana, Vajrasana, and Padmasana. The sessions were held at Visva-Bharati from 7:00 to 8:00 am, Monday to Saturday, under the guidance of certified yoga instructors. The following routine in Table 2 was performed six days a week for eight weeks, with the intensity gradually increasing from the first to the eighth week. The control group maintained their regular daily lifestyle throughout the study. Pre-test data were collected from both groups before the start of the yogic practice program, while post-test data were gathered from all four groups—two experimental and two control—after the eighth week.

Table 2. Yogic practices schedule for six days a week for 8 weeks

Yogasana	1 st & 2 nd	3 rd & 4 th	5 th & 6 th	7 th & 8 th
Suryanamaskar	120×3Rep		120s×6Rep	
Uttanpadasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Pawanmuktasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Naukasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Bhujangasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Ardha dhnurasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Vajrasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Purnasaibhasan	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Virabhadrasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Vrikashana	15s×3rep	30s×3rep	45s×3rep	60s×3rep
Padmasana	15s×3rep	30s×3rep	45s×3rep	60s×3rep

Test Procedure

The kinesthetic obstacle Test measures kinesthetic perception by arranging twelve chairs as obstacles in a 40×5 feet area. Participants first practice walking through the course without a blindfold. They then attempt the course blindfolded, earning 10 points for each station cleared without touching an obstacle. The maximum score achievable is 100 points, as there are ten stations in total.

The storkstand test assesses static balance. The participant stands on their dominant foot, placing the opposite foot's ball against the inside of the supporting knee. Hands rest on the waist. On the start signal, the participant lifts their heel, balancing on the ball of the foot without shifting position. A stopwatch records the time from the start until the balance is lost, marked by the heel touching the ground or a foot shift. The score is the duration in seconds that balance is maintained.

The eye-hand coordination test measures eye-hand coordination ability. The subject stands between two boxes 15 feet apart, with five balls in the left box. On "Go," the subject moves a ball from the left to the right box, repeating

until all balls are transferred. Timing starts with the first "Go" and stops when the last ball is placed in the right box. After a practice trial, two timed trials are given, and the best time is recorded as the score.

Statistical Analysis

For statistical analysis, the Shapiro-Wilk test assessed the normality of data distribution, and Levene's test verified the equality of variances. Descriptive statistics, including the mean and standard deviation (SD), were used, while inferential analysis involved analysis of covariance (ANCOVA), pairwise comparisons, and independent samples t-tests for between-group comparisons. All analyses were conducted using IBM SPSS software at a significance level of 0.05.

Results

The ANCOVA analysis (Table 4) for pre- and post-test data of sedentary women aged 30-40 and 41-50 years showed significant treatment effects across all measured variables.

Table 3. Descriptive statistics of sedentary women aged 30-40 and 41-50 years

Age Group	Group	n	Test	Kinesthetic Obstacle		Static Balance		Coupling Ability	
				Mean	SD	Mean	SD	Mean	SD
30-40	Experimental	15	Pre-test	40.00	5.67	16.67	2.82	22.89	0.90
			Post-test	49.00	6.87	21.40	3.04	21.84	0.71
	Control	15	Pre-test	40.33	5.81	16.33	2.23	23.04	0.94
			Post-test	45.67	6.78	19.33	2.44	22.44	0.60
41-50	Experimental	15	Pre-test	39.00	6.32	15.73	2.89	24.47	1.53
			Post-test	47.67	8.42	19.53	3.42	22.98	1.26
	Control	15	Pre-test	38.67	6.02	13.93	2.66	24.53	1.14
			Post-test	44.33	7.81	16.53	2.70	23.57	1.24

Table 4. ANCOVA for pre-and post-test data of sedentary women aged 30-40 and 41-50 years

Test	Age Group	Source	df	Sum of Squares	Mean Square	F-value
Kinesthetic Obstacle	30-40	Treatment Group	1	99.720	99.720	
		Error	27	480.442	17.794	5.60*
		Total	28	580.162		
	41-50	Treatment Group	1	65.026	65.026	
		Error	27	389.245	14.416	4.51*
		Total	28	454.271		
Static Balance	30-40	Treatment Group	1	24.697	24.697	
		Error	27	113.051	4.187	5.90*
		Total	28	137.748		
	41-50	Treatment Group	1	9.466	9.466	
		Error	27	51.985	1.925	4.92*
		Total	28	61.451		
Coupling Ability	30-40	Treatment Group	1	1.987	1.987	
		Error	27	4.997	0.185	10.74*
		Total	28	6.985		
	41-50	Treatment Group	1	2.175	2.175	
		Error	27	7.723	0.286	7.60*
		Total	28	9.898		

Table value of F (1,27) = 4.22*. Significant at the .05 level

Table 5. Pairwise comparisons of age groups 30-40 and 41-50 of adjusted means in pre-test and post-test data

Test	Age Group	Group	n	Pre-test	Post-test	Mean Adjusted	Mean Difference	Critical Difference
Kinesthetic Obstacle	30-40	Experimental	15	40.00	49.00	49.16	3.65*	2.62
		Control	15	40.33	45.67	45.51		
	41-50	Experimental	15	39.00	47.67	47.47	2.95*	2.36
		Control	15	38.67	44.33	44.53		
Static Balance	30-40	Experimental	15	16.67	21.40	21.28	1.82*	1.27
		Control	15	16.33	19.33	19.46		
	41-50	Experimental	15	15.73	19.53	18.63	1.18*	0.86
		Control	15	13.93	16.53	17.44		
Coupling Ability	30-40	Experimental	15	22.89	21.84	21.88	0.52*	0.27
		Control	15	23.04	22.44	22.40		
	41-50	Experimental	15	24.47	22.98	23.01	0.53*	0.33
		Control	15	24.53	23.57	23.54		

*. The mean difference is significant at the 0.05 level

Table 6. Independent t-test of pre-test and post-test mean differences between age groups 30-40 and 41-50years

Test	Age Group	Group	Pre-Post Mean Difference	Mean Difference	Std Error of Diff	t	Sig.
Kinesthetic Obstacle	30-40	Experimental	9.00	0.33	0.18	1.85	0.86
	41-50	Experimental	8.67				
Static Balance	30-40	Experimental	4.73	0.93	0.71	1.31	0.20
	41-50	Experimental	3.80				
Coupling Ability	30-40	Experimental	1.05	0.453	0.25	1.83	0.08
	41-50	Experimental	1.49				

For the kinesthetic obstacle test, significant differences were observed in both age groups, with F-values of 5.60 ($p < .05$) for ages 30-40 and 4.51 ($p < .05$) for ages 41-50, indicating the treatment improved kinesthetic perception. In static balance, the treatment led to significant improvements, with F-values of 5.90 ($p < .05$) for ages 30-40 and 4.92 ($p < .05$) for ages 41-50, showing enhanced static balance in both groups. For coupling ability, significant effects were also found, with F-values of 10.74 ($p < .05$) for ages 30-40 and 7.60 ($p < .05$) for ages 41-50. Overall, the intervention significantly improved kinesthetic perception, static balance, and coupling ability in both age groups.

The results of pairwise comparisons (Table 5) showed significant differences in adjusted post-test means between age groups 30-40 and 41-50 for pre-test and post-test data across all measures. For kinesthetic obstacle, both age groups had significantly higher post-test adjusted means in the experimental groups compared to the control groups (30-40: mean difference = 3.65, $p < .05$; 41-50: mean difference = 2.95, $p < .05$). A similar pattern was observed for static balance (30-40: mean difference = 1.82, $p < .05$; 41-50: mean difference = 1.18, $p < .05$), and for coupling ability (30-40: mean difference = 0.52, $p < .05$; 41-50: mean difference = 0.53, $p < .05$), with all mean differences exceeding the critical value. These findings indicate that the intervention led to significant improvements across all tested variables for both age groups.

An independent t-test was conducted to compare the experimental group's pre-test and post-test mean differences between the age groups 30-40 and 41-50 across three measures: kinesthetic obstacle, static balance, and coupling ability. No significant differences were found for any of the measures. For the kinesthetic obstacle, the mean difference between the groups was 0.33 ($t = 1.85$, $p = .86$). For static balance, the mean difference was 0.93 ($t = 1.31$, $p = .20$). Lastly, for coupling ability, the mean difference was 0.45 ($t = 1.83$, $p = .08$). These results indicate that both age groups showed similar levels of improvement across all measures.

Discussions

The present study provides compelling evidence that an eight-week yogic intervention significantly enhances kinesthetic perception among sedentary women aged 30–40 years and 41-50 years. This indicates that yogic practices effectively refine proprioceptive acuity and neuromuscular coordination. These findings contribute to the growing body of research supporting the role of yogic practice in improving sensorimotor function in sedentary populations.

Kinesthetic perception is integral to motor control, postural stability, and functional movement. Prior studies have established a strong association between yogic practice and enhanced sensorimotor integration (Rivest-Gadbois & Bou-

drias, 2019). Researchers Singh et al. (2009) reported significant improvements in kinesthetic perception following yogic practice, aligning with the present findings. Additionally, a study highlighted the efficacy of yogic practice in improving body awareness (Gunnersen et al., 2022), and neuromuscular function (Artchoudane et al., 2021), reinforcing the observed benefits in kinesthetic perception. These neurophysiological adaptations have been widely recognized for their role in enhancing proprioception and movement efficiency, particularly in individuals with sedentary lifestyles. Notably, the differential improvements across age groups indicate slightly greater enhancements in kinesthetic perception in the younger cohort, potentially due to higher neuroplasticity (Paraskevopoulos & Herholz, 2013). However, the significant gains observed in the 41–50 age groups underscore the capacity for neurophysiological adaptations to targeted interventions even in the later stages of adulthood. This finding is particularly relevant in the context of age-related declines in proprioceptive function and neuromuscular control, suggesting that yogic practices may serve as an effective intervention to mitigate these declines and promote functional mobility across different age groups. These results have important implications for health promotion and rehabilitation. Given the detrimental effects of prolonged sedentary behavior on kinesthetic perception and motor function, yogic practice emerges as a viable, non-pharmacological approach to counteract these effects. The incorporation of yogic practice-based interventions in routine physical activity regimens could offer substantial benefits in enhancing proprioception, postural stability, and movement efficiency in sedentary populations.

Static balance in sedentary women aged 30–40 and 41–50 years, demonstrated significant improvements in both age groups, as indicated by the ANCOVA findings (Table 4), with F-values of 5.90 ($p < .05$) and 4.92 ($p < .05$), respectively. The findings of this study support yogic practice as an effective intervention for enhancing static balance and postural control in sedentary women. The observed improvements align with prior research (Bajaj et al., 2025), highlighting the role of yogic practice in neuromuscular coordination (Wahyuni et al., 2024), proprioception (Wooten et al., 2018), and core stability (Omkar et al., 2009). The controlled postures, synchronized breathing, and heightened body awareness inherent in yogic practice facilitate sensory integration (Rivest-Gadbois & Boudrias, 2019) and motor control (Kanaujia & Srivastava, 2024), contributing to improved balance and a reduced risk of falls. Yogic practice-based interventions significantly enhance postural stability across different populations, reinforcing their effectiveness in balance training (Jeter et al., 2015; Ikai et al., 2013). Given its accessibility and adaptability, yogic practice presents a practical and non-invasive intervention for balance enhancement, with potential applications in community-based health initiatives aimed at reducing fall-related risks among sedentary populations. Additionally, future research should investigate the long-term retention of balance improvements and incorporate objective biomechanical assessments to provide further insights into the underlying mechanisms.

The coupling ability demonstrated statistically significant improvements across both age groups, respectively. These results align with existing literature Umesh and Suresh (2018), suggesting that structured yogic practices can effectively enhance neuromuscular coordination (Wahyuni et al., 2024), and motor control (Kanaujia & Srivastava, 2024)

in sedentary populations. Coupling ability, which refers to coordinating and integrating movement patterns efficiently, is critical for overall motor performance and daily functional activities. The observed improvements may be attributed to the dynamic nature of yogic practices, which contribute to enhanced proprioceptive awareness (Cherup et al., 2021) and sensor motor integration (Campbell & Martin, 2017). Prior research has suggested that yogic practice likely facilitated the smooth functioning of the central nervous system, enhancing muscle tone and neuromuscular coordination, thereby improving coupling ability (Umesh & Suresh, 2018). The significant treatment effects observed in the present study corroborate these findings, reinforcing the role of yogic practice in augmenting coordinative efficiency. Age-related differences in motor coordination have been widely documented, with middle-aged individuals often exhibiting a decline in neuromuscular adaptability compared to younger counterparts (Wu et al., 2016). Interestingly, our study found that both age cohorts experienced significant improvements in coupling ability, suggesting that yogic interventions can counteract the deleterious effects of sedentary behavior irrespective of age. However, the relatively lower F-value for the 41–50 age group may indicate a slightly reduced responsiveness to the intervention, possibly due to age-associated declines in neuroplastic potential (Ghasemian-Shirvan et al., 2020), and musculoskeletal flexibility (Nolan et al., 2010).

The implications of these findings are noteworthy for public health and physical education, particularly in the context of designing intervention programs aimed at improving bio-motor fitness among sedentary individuals. Given the holistic nature of yogic practices, their integration into fitness regimens may serve as a viable strategy for enhancing coordination and overall physical well-being without the need for high-impact or strenuous physical activity. The observed benefits underscore the necessity of integrating yogic practice-based interventions into public health initiatives and wellness programs aimed at mitigating the adverse effects of a sedentary lifestyle.

Conclusions

An eight-week yogic intervention significantly enhanced kinesthetic perception, static balance, and coupling ability in sedentary women aged 30–50, highlighting its role in improving neuromuscular coordination. These results suggest that yogic practice is a viable approach for enhancing motor functions in non-athletic middle-aged individuals.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Йогічна практика покращує нервово-м'язову координацію у жінок середнього віку, які ведуть малорухливий спосіб життя: Експериментальне дослідження

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 8 с., 6 табл., 1 рис., 52 джерела.

Історія питання. Кінестетичне сприйняття, статична рівновага та здатність до узгодженості рухових дій є невід'ємними складовими координації рухів, зокрема у жінок середнього віку, які ведуть малорухливий спосіб життя. Йогічна практика є широко визнаною методикою, що є ефективною у покращенні фізичних та нервово-м'язових функцій, проте її конкретний вплив на вищезазначені показники залишається недостатньо дослідженим.

Мета дослідження. Метою цього дослідження було оцінити вплив восьмитижневої практики йоги на кінестетичне сприйняття, статичну рівновагу та здатність до узгодженості рухових дій серед жінок середнього віку, які ведуть малорухливий спосіб життя.

Матеріали та методи. Шістдесят жінок, які вели малорухливий спосіб життя, віком від 30 до 50 років, було цілеспрямовано відібрано зі штату Західна Бенгалія, Індія, та розділено на дві вікові групи (30–40 та 41–50 років). Кожна вікова група була додатково розподілена на експериментальну групу (n = 15) та контрольну групу (n = 15). Експериментальні групи брали участь у структурованій програмі з йогічної практики протягом восьми тижнів, тоді як контрольні групи продовжували свою звичайну активність. Кінестетичне сприйняття, статична рівновага та здатність до узгодженості рухових дій оцінювалися за допомогою кінестетичного тесту на перешкоди, тесту на рівновагу «Лелека» та тесту на координацію рук і очей відповідно. Статистичні аналізи, включаючи коваріаційний аналіз, парні порівняння та t-критерії для незалежних вибірок, було проведено за допомогою програмного забезпечення SPSS із рівнем значущості 0.05.

Результати. Коваріаційний аналіз виявив значне поліпшення показників у кінестетичному сприйнятті (F = 5.60, p < 0.05; F = 4.51, p < 0.05), статичній рівновазі (F = 5.90, p < 0.05; F = 4.92, p < 0.05) та здатності до узгодженості рухових дій (F = 10.74, p < 0.05; F = 7.60, p < 0.05) для експериментальних груп у вікових діапазонах 30-40 та 41-50 років відповідно, порівнюючи з контрольними групами. Парні порівняння підтвердили ці суттєві відмінності, тоді як t-критерії для незалежних вибірок не показали істотних варіацій між віковими групами в експериментальних групах.

Висновки. Дослідження показало, що восьмитижнева практика йоги сприяла значному поліпшенню кінестетичного сприйняття, статичної рівноваги та здатності до узгодженості рухових дій у жінок середнього віку, які ведуть малорухливий спосіб життя, продемонструвавши свою ефективність у підвищенні нервово-м'язової координації. Отримані результати підтверджують, що йогічна практика є ефективною стратегією щодо покращення рухових функцій у групах дорослого населення, які не займаються спортом.

Ключові слова: йогічна практика, кінестетичне сприйняття, статична рівновага, здатність до узгодженості рухових дій, жінки середнього віку.

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Identifying the Acute Effects of Plyometric and Contrast Training on Acceleration and Agility in Young Rugby Players: A Randomized Controlled Trial

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Abstract

Objectives. The present study examined the impact of a single session of plyometric training (PT) and contrast training (CT) on speed, agility, and power in young rugby players. The objective of this study was to ascertain which method produced better immediate improvements.

Materials and methods. Thirty male rugby players at the national level (average age 14.3 years, height 1.51 meters, weight 48.63 kg) took part in the study. The participants were randomly divided into two groups: 15 individuals were assigned to a plyometric training plan, while the remaining 15 followed a contrast training routine. Before and after the training session, each athlete was subjected to testing for sprint speed (5 m, 10 m, and 20 m), agility (assessed using the Illinois Agility Test), jump height (measured via the countermovement jump, CMJ), and explosive leg power (evaluated with reactive strength index, RSI). The plyometric protocol consisted of depth jumps, bounding, hurdle hops, lateral bounds, and spring-loaded drop jumps, while the contrast protocol paired heavy resistance exercises (85% 1RM) with biomechanically similar plyometric movements.

Results. Both interventions produced significant acute improvements across all performance metrics ($p < 0.05$). The CTG demonstrated superior enhancements compared to the PTG in 5m sprint time (-6.14 % vs. -3.53 %, $p < 0.001$, $\eta^2p = 0.79$), 10m sprint time (-5.37 % vs. -3.76 %, $p < 0.048$, $\eta^2p = 0.68$), 20 m sprint time (-3.90 % vs. -2.60 %, $p < 0.019$, $\eta^2p = 0.18$), agility time (-4.95 % vs. -3.09 %, $p < 0.001$, $\eta^2p = 0.94$), RSI (+8.60 % vs. +5.91 %, $p < 0.001$, $\eta^2p = 0.82$), and CMJ height (+7.40 % vs. +5.79 %, $p < 0.001$, $\eta^2p = 0.36$).

Conclusions. The study concludes that both training modalities acutely enhanced acceleration, agility, and power performance in young rugby players. However, contrast training produced significantly greater improvements across all metrics. The findings indicate that contrast training could be more useful than plyometric training for boosting explosive strength in young rugby players following a single session. This may be associated with triggering stronger short-term improvements in muscle performance.

Keywords: post-activation performance enhancement, youth athletes, sprint performance, change of direction, explosive power, warm-up strategy.

Introduction

Rugby is a demanding, high-intensity sport that involves repeated bouts of sprinting, stopping, changing direction,

and explosive efforts. Players are required to perform with high levels of speed, strength, and agility to succeed on the field (Smart et al., 2014). Quick acceleration over short distances, typically 5 to 20 meters, is especially important during game play. It enables athletes to break through defenses, avoid tackles, or chase down opponents (Barr et al., 2014; Cross et al., 2015a). Agility, which refers to the swift ability to change direction while staying balanced and

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in control, is also a critical aspect of rugby performance (Sheppard & Young, 2006). Because of these physical demands, coaches and trainers have placed increased emphasis on specific training methods that target these abilities (Beaven et al., 2011). To improve such qualities, strength and conditioning professionals have adopted strategies like plyometric and contrast training. (Baker, 2001; Markovic & Mikulic, 2010). Plyometric exercises rely on the stretch-shortening cycle (SSC) to improve explosive strength and the rate at which force is developed, called rate of force development (RFD) (Markovic & Mikulic, 2010). These drills often involve jumping, hopping, and bounding exercises that make use of the SSC. These movements take advantage of the elastic energy stored during the muscle's eccentric phase to boost force production in the following concentric phase (Cormie et al., 2011). Studies have shown that incorporating plyometrics into training programs can lead to gains in vertical jump height, sprint acceleration, and directional agility, especially in athletes involved in team sports (Asadi et al., 2016; Ramírez-Campillo et al., 2015). Contrast training, alternatively, blends heavy resistance lifts with plyometric actions that mimic the same movement patterns. This approach is thought to trigger post-activation performance enhancement (PAPE), thereby improving the body's ability to generate power more effectively within the same session (Docherty & Hodgson, 2007; Tillin & Bishop, 2009). This method aims to exploit the acute neuromuscular potentiation following near-maximal muscle contractions, potentially leading to enhanced performance in subsequent explosive activities (Robbins, 2005; Seitz & Haff, 2016a). While both training methodologies have shown promise for improving athletic performance, there remains uncertainty regarding their comparative acute effects (Hammami et al., 2019a) which is also true in the case of young rugby players. The reactive strength index (RSI) and countermovement jump (CMJ) have been established as valid measures of lower limb explosive power (Flanagan & Comyns, 2008), while sprint times over various distances (5m, 10m, 20m) represent key performance indicators in rugby (West et al., 2013). However, the immediate responses to these training stimuli and their potential to acutely enhance these performance metrics warrant further investigation.

The majority of existing research has focused on chronic adaptations to these training modalities, with comparatively less attention given to their acute effects (Lockie et al., 2012; Tobin & Delahunt, 2014). Understanding the immediate performance changes following plyometric and contrast training sessions could provide valuable insights for coaches when designing pre competition warm up protocols or implementing in-season training strategies that aim to maximize performance without inducing excessive fatigue (McGowan et al., 2015). The developmental stage of young athletes presents another important consideration, as responses to training stimuli may differ significantly from those observed in adult populations (Lloyd et al., 2016). Adolescent rugby players are still developing physiologically, potentially influencing their neuromuscular responses to different training modalities (Moran et al., 2017). However, not much research has looked at how these training methods affect young rugby players in the short term. There's clearly a lack of studies in this area (Noon et al., 2015). This study aimed to fill that gap by conducting a randomized controlled

trial comparing the immediate impact of plyometric and contrast training on several performance metrics. Specifically, we examined how these interventions influenced sprint acceleration over 5, 10, and 20 meters, agility, RSI, and CMJ height in adolescent rugby players. The goal was to provide insights into how different explosive training techniques can acutely affect physical performance in this age group. Such findings could help coaches and practitioners refine their training programs and warm-up routines to better prepare young athletes for match demands.

Materials and Methods

Study Participants

The study included 30 adolescent male rugby players, all of whom competed at the national level. Participants were randomly divided into two groups of equal size: a Plyometric Training Group (PTG; $n = 15$) and a Contrast Training Group (CTG; $n = 15$). An a priori power analysis was carried out using G*Power software (version 3.1.9.7; Universität Kiel, Germany), as recommended by Kang, (2021) The analysis determined that a minimum of 20 participants would be sufficient to detect a moderate effect size ($f = 0.25$) with 80% statistical power and an alpha level of 0.05, using a repeated measures ANOVA for within-between interactions. All athletes had at least three years of competitive rugby experience. Since participants were minors and the intervention took place in Gwalior, Madhya Pradesh, parental consent was obtained remotely. The team coach and manager, acting as local guardians, gave their consent and were present during the sessions. Before the study began, both the players and their guardians were clearly told what the study involved, its purpose, steps, risks, and possible benefits. Participation was voluntary, and subjects could opt out at any point without any negative repercussions. Strict confidentiality was maintained throughout the research. To keep the players safe, qualified strength and conditioning coaches oversaw all sessions. Warm-ups were required, and medical help was available on-site. The research followed the ethical standards of the Declaration of Helsinki (World Medical Association, 2013). The data collection for all athletes was conducted in the month of February 2025.

Table 1. General details of the participants (average $\pm$ standard deviation), total number = 30

Age (Y)	Height (mt)	Weight (kg)	BMI
14.30 $\pm$ 0.98	1.51 $\pm$ 0.02	48.63 $\pm$ 2.55	21.20 $\pm$ 0.91

Study Organization

A randomized controlled trial design was employed to investigate the acute effects of plyometric and contrast training on acceleration and agility. Pre- and post-test measurements were conducted within a single training session to assess immediate neuromuscular adaptations. Participants attended two preliminary sessions: the first for familiarization with testing procedures and training exercises, and the second (72 hours later) for determining one-repetition maximum (1RM) values for resistance exercises used in the contrast training protocol. The

experimental session was conducted after a 72-hour recovery period following 1RM testing.

Familiarization Session

In the familiarization session, the athletes were shown how all the tests and exercises would be done. This helped minimize any learning effects. They performed submaximal efforts of all tests (sprints, Illinois Agility Test, drop jumps, and CMJ) and practiced the execution of all training exercises with proper technique under supervision.

One-Repetition Maximum (1RM) Testing

The 1RM values for back squat, trap bar deadlift, and lateral step-ups were determined following the protocol described by Haff and Triplett (2021) (Haff & Triplett, 2021). After a standardized warm-up, participants performed progressively heavier loads until they reached their 1RM within 3-5 attempts, with 3-5 minutes of rest between attempts. For safety considerations with adolescent participants, a conservative approach was taken where technical failure was used as the endpoint rather than absolute muscular failure.

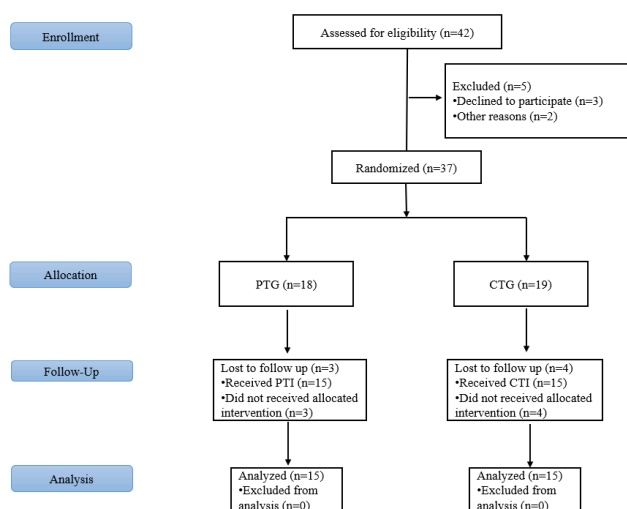


Fig. 1. Inclusion and Exclusion Criteria

Training Intervention

Each group underwent a structured warm-up followed by their respective training protocols:

Plyometric Training Group

This group performed a series of explosive bodyweight exercises designed to enhance SSC efficiency and reactive strength. The session included:

The acute plyometric training program presented in Table 2 was specifically designed for adolescent rugby players, aiming to improve explosive strength, reactive capability, and the efficiency of the SSC. These physical attributes are essential for key actions in rugby such as sprinting, tackling, and quick directional shifts.

Table 2. Plyometric Training Plan for Young Rugby Players

Exercise	Sets	Reps/Distance
Depth Jumps	3	5 reps
Bounding	3	20m
Hurdle Hops	3	5 reps
Lateral Bounds	3	10 reps per leg
Sprint Loaded Drop Jumps	3	4 reps
Rest Period	90 sec between sets, 3 min between exercises	

The session consisted of five targeted exercises. Depth Jumps (3 sets of 5 repetitions) were included to enhance vertical power and optimize SSC utilization. Bounding drills (3 sets covering 20 meters) focused on improving horizontal force production and increasing stride length.

Hurdle Hops (3 sets of 5 reps) were incorporated to build rhythm, coordination, and vertical explosiveness. Lateral Bounds (3 sets of 10 reps for each leg) aimed at reinforcing lateral stability and agility. In addition, Sprint Loaded Drop Jumps (3 sets of 4 repetitions) were used to replicate sport-specific explosive movements and transitions on the field.

To promote recovery and maintain high-quality performance, 90 seconds of rest was provided between sets and 3 minutes between each exercise. This structure also serves to minimize the risk of injury during the session.

Contrast Training Group

The contrast training protocol for this group was based on the principle of post-activation potentiation (PAP), involving the pairing of high-load resistance exercises with explosive plyometric movements. The session included:

Table 3. Contrast Training Plan for Young Rugby Players

Exercise	Sets	Reps/Distance
Back Squat (85% 1RM) + Box Jumps	3	3 reps + 5 reps
Trap Bar Deadlift (85% 1RM) + Hurdle Hops	3	3 reps + 5 reps
Sled Push + Sprint	3	20m + 20m
Lateral Step-Ups (80% 1RM) + Lateral Bounds	3	3 reps per leg + 8 reps per leg
Rest Period	90 sec between sets, 3 min between exercises	

As outlined in the session included four key contrast pairings. The first pair involved the Back Squat performed at 85% of one-repetition maximum (1RM), immediately followed by Box Jumps. Each pairing was completed for 3 sets, with 3 reps of squats and 5 reps of jumps. This combination was selected to boost lower limb strength and vertical explosive power.

Next athletes performed Trap Bar Deadlifts (85% 1RM) paired with Hurdle Hops, again using the 3x3 and 3x5 set-rep structure. This sequence was designed to strengthen the posterior chain and improve reactive force output.

The third pairing included Sled Pushes and short-distance Sprints, each performed over 20 meters for 3 sets, targeting acceleration and horizontal power production. The final contrast set combined Lateral Step-Ups at 80% 1RM with Lateral Bounds, 3 reps per leg for the resistance work and 8 reps per leg for the plyometric drill. This pairing aimed to build unilateral leg strength and support agile lateral movements.

Rest periods were built into the session to optimize training quality: 90 seconds between sets and 3 minutes between each contrast pairing. The entire session lasted around 38 minutes, matching the duration of the plyometric training protocol to ensure both groups could train concurrently with equal workload distribution.

Measurements and Data Collection

To evaluate the immediate impact of the training protocols, performance tests were carried out both before and right after the intervention. These tests focused on key physical attributes: acceleration, agility, reactive strength, and lower body power. Acceleration was measured using sprint tests over 5, 10, and 20 meters. Electronic timing gates were employed to capture precise and consistent timing data, ensuring measurement accuracy (Cross et al., 2015b). Agility was assessed using the Illinois Agility Test, a widely recognized tool for assessing multidirectional movement and rapid changes in direction (Lockie et al., 2013). This test is commonly used in sport performance settings due to its reliability. Reactive strength was examined using the RSI, calculated from drop jump performance. This metric reflects the efficiency of the SSC (Byrne et al., 2017), offering insight into an athlete's ability to switch quickly from eccentric to concentric muscle action. Lower limb power was assessed using the CMJ, providing insight into explosive strength and neuromuscular performance (McMahon et al., 2018). To maintain consistency and data integrity, all assessments were conducted under standardized conditions by trained professionals, ensuring high reliability and validity in measurement outcomes.

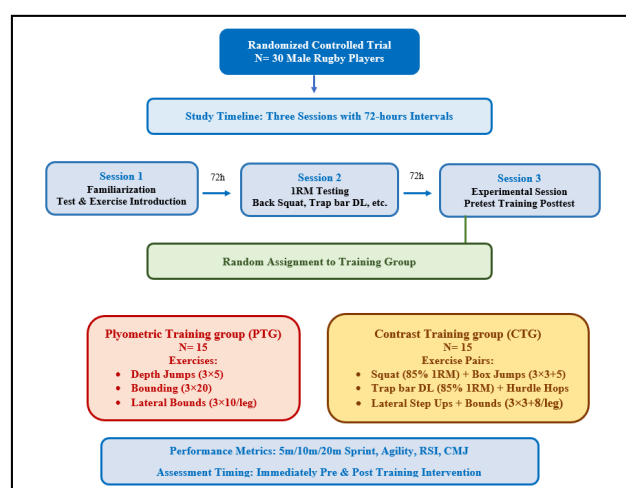


Fig. 2. Study Methodology and Design Flowchart

Statistical Analysis

The statistical evaluation was performed using IBM SPSS (Version 29.0.0, IBM Corp., New York, USA). To check for

normal distribution in the dataset, the Shapiro-Wilk test was employed. Descriptive statistics, such as mean, median, and standard deviation, were calculated to provide an overview of the data. These measures helped in identifying central trends and variability in performance metrics. A repeated measures ANOVA was applied to examine both within-group and between-group differences across time points. This allowed for detection of any interaction effects between the training method and performance outcomes. Effect sizes for the main and interaction effects were reported using partial eta squared (η^2). These were interpreted as small (<0.06), moderate (0.06 to 0.13), or large (≥ 0.14), in line with the guidelines from (Saha et al., 2025). All statistical analyses were conducted using a predetermined alpha level of 0.05 to determine significance.

Results

The study protocol was completed by all the 30 participants with no adverse events reported. Descriptive statistics and results from the repeated measures ANOVA are presented in Table 4 and Figure 1.

The Table 4 outlines the immediate effects of the two training interventions, PTG and CTG on key performance indicators such as sprint times (5 m, 10 m, and 20 m), agility, RSI, and CMJ height. Both groups showed noticeable improvements in sprint performance over all measured distances. The times for 5 m, 10 m, and 20 m sprints were significantly reduced post-training in each group. However, athletes in the CTG displayed more pronounced gains. Specifically, CTG participants recorded a 6.14 % drop in 5 m sprint time, a 5.37 % decrease over 10m, and a 3.90 % improvement at the 20 m mark, indicating more effective acceleration enhancements compared to PTG. The PTG also showed notable improvements, with reductions of 3.53 % (5 m), 3.76 % (10 m), and 2.60 % (20 m). Statistical analysis confirmed significant effects, with F-values ranging from 4.25 to 107.67 and p-values below 0.05, indicating meaningful performance enhancements. Agility improvements were more pronounced in the CTG than in the PTG. The CTG showed a 4.95 % reduction in agility time, whereas the PTG recorded a 3.09 % reduction. A highly significant effect ($F = 442.86$, $p < 0.001$, $\eta^2 p = 0.94$) was observed, demonstrating the substantial impact of both training modalities, with CTG yielding superior agility gains. The RSI, a key measure of explosive strength and neuromuscular efficiency, showed a greater increase in the CTG (8.60 %) compared to the PTG (5.91 %). The statistical analysis revealed a strong effect size ($F = 127.94$, $p < 0.001$, $\eta^2 p = 0.82$), highlighting the effectiveness of complex training in enhancing rapid force production. CMJ performance, indicative of lower-limb power, exhibited improvements in both groups, with the CTG achieving a 7.40 % increase and the PTG a 5.79 % increase. The effect size was moderate ($\eta^2 p = 0.36$, $F = 15.95$, $p < 0.001$), suggesting that complex training provides a marginal advantage in jump performance over plyometric training alone.

Discussion

The primary objective of this research was to explore how a single session of plyometric and contrast training acutely

Table 4. Pre- and Post-Test Performance Analysis of Sprint Speed, Agility, Reactive Strength, and Jump Performance in Plyometric and Complex Training Groups

Variables	Groups	Pre data	Post data	Δ (%)	SS	F	p	η^2p
5mt Sprint	PTG	1.13 $\pm$.016	1.09 $\pm$.018	-3.53	.002	107.67	<0.001*	.79
	CTG	1.14 $\pm$.012	1.07 $\pm$.014	-6.14				
10mt Sprint	PTG	1.86 $\pm$.016	1.79 $\pm$.018	-3.76	.002	4.25	<0.048*	.68
	CTG	1.86 $\pm$.014	1.76 $\pm$.015	-5.37				
20mt Sprint	PTG	3.07 $\pm$.025	2.99 $\pm$.037	-2.60	.007	6.25	<0.019*	.18
	CTG	3.07 $\pm$.022	2.95 $\pm$.023	-3.90				
Agility	PTG	17.14 $\pm$.021	16.61 $\pm$.025	-3.09	.339	442.86	<0.001*	.94
	CTG	17.15 $\pm$.023	16.30 $\pm$.035	-4.95				
RSI	PTG	1.86 $\pm$.011	1.97 $\pm$.013	5.91	.010	127.94	<0.001*	.82
	CTG	1.86 $\pm$.011	2.02 $\pm$.016	8.60				
CMJ	PTG	38.48 $\pm$.035	40.71 $\pm$.470	5.79	1.398	15.95	<0.001*	.36
	CTG	38.48 $\pm$.042	41.33 $\pm$.345	7.40				

influences short-distance sprinting, agility, RSI, and CMJ height in adolescent rugby players. Both training modalities led to significant improvements across all parameters, with contrast training demonstrating consistently greater gains. To put numbers on it, the CTG group reduced their 5 m sprint times by 6.14% while PTG improved by 3.53%. Similarly, for 10 m sprints, CTG dropped 5.37%, compared to PTG's 3.76%. At 20 m, CTG saw a 3.90% reduction, PTG just 2.60%. In agility, CTG improved 4.95%, PTG by 3.09%. RSI and CMJ followed the same trend. The CTG had an 8.60% increase in RSI versus 5.91% in PTG. CMJ height rose 7.40% in CTG, 5.79% in PTG. These results are consistent with what earlier research has shown on PAPE, which suggest that muscle output can temporarily improve after engaging in heavy or intense conditioning exercises (Blazevich & Babault, 2019). PAPE describes a short-lived increase in muscular performance triggered by a preceding high-intensity activity. (Blazevich & Babault, 2019). In contrast training, the combination of heavy resistance followed by explosive movement appears to more effectively activate this mechanism than plyometric exercises alone. This sequence likely "primes" the neuromuscular system, enabling greater power output during subsequent high-velocity movements (Seitz & Haff, 2016b). One explanation for CTG's superior results is the more robust recruitment of high-threshold motor units, particularly Type II (fast-twitch) fibres, which are essential for producing rapid and forceful contractions (Hodgson, et al., 2005). While plyometric training alone can also activate these fibres, the inclusion of heavy resistance work may provide a more intense and effective stimulus (Barra-Moura et al., 2024). On a neural level, contrast training enhances corticospinal excitability and reduces inhibitory reflexes, improving the nervous system's efficiency in quickly activating the muscles (Lorenz, 2011). This likely played a significant role in the improved RSI and short sprint performance, especially in the 5 and 10 m tests where explosive starts are critical. Bevan et al., (2010) reported similar results, finding that heavy back squats improved sprint times in elite rugby players.

Mechanically, contrast training may increase musculotendinous stiffness, enhancing the SSC. A stiffer

muscle-tendon unit facilitates quicker and more efficient force transmission, which is particularly beneficial for sprinting, jumping, and direction changes (Ramírez-delaCruz et al., 2022). While plyometric movements already utilize the SSC, the heavy pre-load in contrast training likely improves elastic energy storage and utilization during the explosive phase (Hammami et al., 2019b). There may also be a psychological component. Lifting heavy loads before performing explosive tasks can increase arousal and focus, temporarily boosting performance (Gould, 2021). Though this area is less studied, it's frequently cited by coaches and athletes as a practical advantage of contrast or complex training. Contrast training offers a more holistic and powerful stimulus, producing more noticeable short-term performance improvements. Notably, this appears to be the first study directly comparing the acute effects of plyometric and contrast training in adolescent rugby players. Although this limits direct comparison with prior work, parallels can be drawn. Jeffreys, et al., (2019) reported RSI improvements in collegiate rugby players following both high- and low-volume plyometric programs. Although their intervention lasted several weeks and involved older athletes, the 5.91% RSI improvement observed in our PTG after just one session echoes their conclusion that even low-volume protocols can be effective. Interestingly, our CTG's RSI improvement of 8.60% exceeded Jeffreys' long-term gains, likely due to the immediate potentiation effect of combining resistance and explosive exercises.

Vissing et al., (2008) reported that plyometric training led to greater improvements in muscle power compared to resistance training among untrained young men. This observation is consistent with the outcomes seen in our PTG. Interestingly, CTG demonstrated even greater acute performance gains. This suggests that combining resistance and plyometric exercises may provide a more effective stimulus for neuromuscular activation. It's important to mention that Vissing's study involved untrained adults, whereas our participants were trained adolescent athletes, this difference in training background may partly explain the variation in results. Additional support comes from Huang et al., (2023) and Chikhalkar, (2018), who found

plyometric training improved speed, agility, and explosive strength in elite and adolescent basketball players, respectively. While the populations and sports differ, the underlying neuromuscular adaptations appear comparable. Our CMJ findings also resonate with those of Vissing et al., (2008), who demonstrated that plyometric training effectively boosts jump performance. The enhanced jump height in both PTG and CTG, particularly after a single session, underscores the responsiveness of explosive power to acute neuromuscular stimuli. These improvements likely contributed to the observed sprint gains, as increased reactive strength and vertical power are closely tied to acceleration capability. When it comes to agility, our findings may be among the first to document acute improvements following a single PT or CT session. Both CT and PT programs lasting 6-12 weeks have been shown to improve agility and change of direction ability in youth soccer and basketball players (García-Pinillos et al., 2014; Latorre Román et al., 2017). The improvements in Illinois Agility Test scores add new evidence that both training types can immediately enhance change-of-direction ability, with contrast training again proving more effective. From an applied perspective, the outcomes of this study offer valuable insights for coaching practices. When time is limited, such as before a game or during a tapering phase, contrast training could serve as a time-efficient tool to boost short-term performance. Its effects are immediate and multifaceted, making it a smart option for enhancing speed, agility, and power on short notice. This study has limitations. It focused solely on male adolescent rugby players, limiting generalizability. The intervention assessed only acute effects, without examining long-term adaptations. Additionally, muscle activity was not measured directly, which leaves gaps in our understanding of underlying physiological mechanisms. Future research should explore different age groups, sports, and genders, while incorporating electromyographic and hormonal markers for deeper insight.

Conclusions

Both PTG and CTG produced immediate performance improvements in sprint speed, agility, RSI, and CMJ height. However, contrast training consistently resulted in greater gains, likely due to its ability to stimulate both neural and muscular systems more effectively. For coaches aiming to optimize short-term athletic performance in youth rugby or similar sports, contrast training presents a potent and practical strategy.

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Conflict of interest

The authors declare no conflict of interest.

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Визначення безпосереднього впливу пліометричного та контрастного тренування на показники прискорення та швидкості юних регбістів: Рандомізоване контрольоване дослідження

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 4 табл., 2 рис., 46 джерел.

Мета дослідження. У представленому дослідженні вивчався вплив проведення одного заняття з пліометричного тренування (ПТ) та контрастного тренування (КТ) на показники швидкості, швидкості та потужності у юних регбістів. Метою дослідження було з'ясувати, яка з зазначених методик забезпечує більшу ефективність з точки зору поліпшення безпосередніх результатів.

Матеріали та методи. У дослідженні взяли участь 30 регбістів національного рівня чоловічої статі (середній вік 14.3 роки, зріст 1.51 метра, вага 48.63 кг). Учасників було розподілено за методом рандомізації на дві групи: 15 осіб долучилися до плану пліометричних тренувань, а решта 15 — до програми контрастних тренувань. Перед початком та після завершення тренувальної сесії кожен спортсмен проходив тестування на швидкість спринту (5 м, 10 м і 20 м), швидкість (вимірювалась за допомогою Іллінойського тесту на швидкість), висоту стрибка (виконання стрибка з контррухом, СКР) та вибухову потужність ніг (оцінювалась із використанням індексу реактивної сили, ІРС). Пліометричний протокол складався зі стрибків у глибину, стрибків з відштовхуванням й підняттям колін, стрибків через бар'єри, бокових стрибків і стрибків з невеликої платформи із пружним відштовхуванням, тоді як контрастний протокол поєднував інтенсивні силові вправи (85% 1ПМ) з біомеханічно аналогічними пліометричними рухами.

Результати. Обидві інтервенції сприяли значному ефективному поліпшенню за всіма показниками результативності ($p < 0.05$). Група, що виконувала програму контрастних тренувань продемонструвала кращі результати порівняно з

групою пліометричних тренувань щодо показників часу виконання спринту на 5 метрів (-6.14 % проти -3.53 %, $p < 0.001$, $\eta^2p = 0.79$), часу виконання спринту на 10 метрів (-5.37 % проти -3.76 %, $p < 0.048$, $\eta^2p = 0.68$), часу виконання спринту на 20 метрів (-3.90 % проти -2.60 %, $p < 0.019$, $\eta^2p = 0.18$), часу реакції спритності (-4.95 % проти -3.09 %, $p < 0.001$, $\eta^2p = 0.94$), IPC (+8.60 % проти +5.91 %, $p < 0.001$, $\eta^2p = 0.82$) та висоти СКР (+7.40 % проти +5.79 %, $p < 0.001$, $\eta^2p = 0.36$).

Висновки. Проведене дослідження дозволяє зробити висновок, що обидва види тренувань значно покращили показники прискорення, спритності та потужності юних регбістів. Однак виконання контрастного тренування забезпечило значніші поліпшення результатів за всіма показниками. Результати дослідження свідчать, що контрастне тренування може бути ефективнішим за пліометричне тренування з точки зору підвищення вибухової сили у юних регбістів вже після проведення одного заняття. Це може бути пов'язано з активізацією інтенсивніших короткострокових позитивних змін показників м'язової працездатності.

Ключові слова: постактиваційне підвищення результативності, юні спортсмени, спринтерська результативність, зміна напрямку руху, вибухова потужність, стратегія розминки.

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The Effects of Ladder Drill and Plyometric Training on Agility in Futsal Players Considering Body Mass Index

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Abstract

Objectives. This study aimed to investigate the effects of ladder drills and plyometric training on agility among futsal players, considering their Body Mass Index (BMI) classifications.

Materials and methods. Twenty male futsal athletes from Vamos Academy Padang participated in the study and were divided into two groups based on their BMI (high BMI and low BMI groups). Each BMI group was assigned to either ladder drill or plyometric training interventions for six weeks. Agility was assessed using the Illinois Agility Test before and after the intervention. Data analysis included paired and independent t-tests, as well as two-way ANOVA, to evaluate group differences.

Results. Both training interventions significantly improved agility performance ($p < .05$). However, ladder drill training resulted in greater enhancement of agility when compared with plyometric training across all BMI classifications. Moreover, athletes in the low BMI group showed more marked improvements than those in the high BMI group. A significant interaction was found between training type and BMI classification, indicating that body composition influences the effectiveness of agility training programs.

Conclusions. Ladder drill training was more effective than plyometric training for enhancing agility in futsal players, particularly those with a lower BMI. These findings suggest that coaches should consider athletes' BMI when designing agility training programs to optimize performance outcomes.

Keywords: agility, ladder drill, plyometric training, body mass index, motor coordination.

Introduction

Agility is a crucial physical attribute in futsal, characterized by its rapid pace, confined playing space, and constant directional shifts (Ilham et al., 2024a; Setyawan & Peking, 2023; Komang et al., 2024). Dynamic and unpredictable game scenarios may necessitate rapid, unforeseen decelerations, prompt directional changes, and intricate footwork patterns (Hung et al., 2020; Ripoll & Genevois, 2022; Malwanage, 2022).

The physical requirements render agility an essential component of individual performance and a determinant of overall team success in offensive and defensive maneuvers.

In high-intensity games, improved agility gives a competitive edge by enabling players to respond quicker, keep balance under stress, and carry out tactical plays more efficiently (Trecroci et al., 2022; Carvutto, Damasco, & De Candia, 2021; Kováčiková & Zemková, 2020). Developing agility is, therefore, a primary focus in the training of futsal players.

Ladder drill exercises and plyometric training are commonly utilized strategies to improve the neuromuscular and biomechanical components of agile performance (Rasyid et al., 2023; Dave & Singh, 2024; Prakash, Sadvika, & Chakravarthi, 2021; Pramono, Rahayu, & Yudhistira, 2023). Ladder drills involve precise, rapid foot movements across a ground-level ladder, training athletes to synchronize quick steps, control body movements, and maintain balance during swift directional shifts (Ilham et al., 2024a; Liu, 2023; Hanani et al., 2024).

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This training emphasizes rhythm, timing, and fine motor control essential attributes for improving reactive and anticipatory movements in competitive settings (Uehara, Togo, & Hanakawa, 2022; Wang, Frank, Hung, & Schack, 2022; Song et al., 2020).

Plyometric training, by contrast, focuses on developing explosive muscular power through exercises such as jumps, hops, and bounds (Pandoyo et al., 2020; Huang H, Huang W, & Wu, 2023; Wang et al., 2023). By improving the efficiency of the stretch-shortening cycle in muscles, plyometric exercises enhance an athlete's ability to generate force rapidly, contributing to faster takeoffs, quicker decelerations, and more powerful changes in direction (Duchateau & Amiridis, 2023; Roy & Debnath, 2023; Khan, 2023). Plyometric exercises also help build lower body strength and neuromuscular efficiency, which are critical for sustaining high levels of performance throughout the physical demands of a futsal match (Roy & Debnath, 2023; Hasan, 2023; Drouzas et al., 2020).

Although ladder drills and plyometric training have been proven to contribute positively to agility, there is an ongoing discussion regarding which method is more effective for enhancing specific aspects of movement performance (Prakash, Sadvika, & Chakravarthi, 2021; Bassa et al., 2024; Das, 2020; Dave & Singh, 2024). Physical characteristics such as body mass index (BMI) may also influence how athletes respond to different training approaches. BMI, which relates body weight to height, is an important indicator of body composition and physical fitness (Chen, Cui, Zhang, & Peng, 2020; Qin, G., Qin, Y. & Liu, 2022; Mendoza-Muñoz et al., 2020). A higher BMI, especially with higher fat mass, may impair agility by increasing the mechanical load during rapid movements, reducing speed, and limiting the ability to perform quick directional changes (Hidayat et al., 2022; Patel & Thakrar, 2024; Fauziah et al., 2024; Arianti et al., 2025). Conversely, a lower BMI may be associated with improved movement efficiency, better acceleration, and greater ease of movement during dynamic activities (Baillot et al., 2022; Suorsa et al., 2023).

Despite the recognized influence of BMI on physical performance, few studies have examined how BMI interacts with specific agility training methods to affect training outcomes. Whether athletes with different BMI levels benefit differently from ladder drills or plyometric training is valuable for designing more individualized and effective training programs. It also helps maximize players' agility development depending on their physical profiles, improving general team performance and lowering the injury risk connected with ineffective movement patterns.

This study aims to assess the impact of ladder drills and plyometric training on futsal players' agility while considering the possible moderating influence of body mass index.

By closing this gap, the research provides creative ideas to help coaches, trainers, and sports experts choose the most suitable training interventions for athletes with different physical traits, improving their performance potential on the futsal court.

Materials and Methods

Research Design

This study employed a 2×2 factorial design to examine the effects of ladder drills and plyometric training on agility

in futsal players, considering BMI as a moderating factor. The experimental approach allowed for the analysis of the main and the interaction effects of training type and BMI on agility performance. Participants were randomly assigned to one of four groups, ensuring a balanced distribution across conditions. The study lasted six weeks, during which training interventions were applied systematically to measure their impact on agility.

To ensure consistency, certified coaches supervised all training sessions, and the intervention protocol was standardized across groups. Participants were instructed to maintain their diet and avoid additional high-intensity training during the study period to control for external influences.

Table 1. The number of participants in each treatment group

BMI (B)	AF Training (A)				Total (n)
	SJ (A1) LD methods	n	HJ (A2) PT methods	n	
High (B1)	A1B1	5	A2B1	5	10
Low (B2)	A1B2	5	A2B2	5	10
Total	A1	10	A2	10	20

Notes: BMI = Body Mass Index, SJ = snake jump, LD = ladder drill, HJ = hurdle jumps, PT = plyometric training, AF = agility

Participants

The study participants included 38 futsal players from Vamos Academy Padang. Based on BMI percentiles, 27% of the highest and lowest BMI values were selected, resulting in 10 players with high BMI and 10 with low BMI, totaling 20 participants (mean age: 17.2 ± 0.763 years) (Ilham et al., 2024a; Ilham et al., 2024b; Sari et al., 2025). Participants had to meet specific inclusion criteria, including resting heart rate, appropriate oxygen saturation levels, and normal systolic and diastolic blood pressure (SpO_2 : 96-100%). Once the BMI data was collected, further analysis was conducted using the ordinal pairing technique to identify the experimental groups (fig. 1).

Randomization was performed using the A-B-B-A pairing technique to ensure balanced group assignment. The randomization process was conducted using IBM SPSS Version 25, which generated randomized group assignments

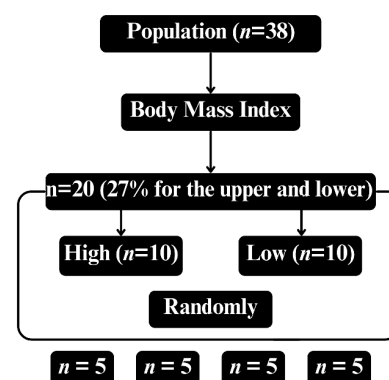


Fig. 1. Methods for assigning participants to treatment groups in the study

to eliminate selection bias. A 30-meter sprint test was conducted, and BMI classification depended on the best and worst outcomes. Participants were then assigned to two groups based on agility levels (Padli et al., 2024; Prasetyo et al., 2024; Selviani et al., 2024). All participants were informed about the study procedures and provided written informed consent prior to participation. For participants under the age of 18, the written consent of the parent or legal guardian and the verbal or written consent of the minor has been obtained in accordance with applicable ethical and legal requirements. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University of Negeri Padang (13.02/KEP-UNP/5/2024).

Training Protocol

The intervention lasted six weeks, with training sessions held three times per week. Each session commenced with a 10-minute warm-up incorporating static and dynamic stretching exercises. The primary agility training lasted 30 minutes, during which participants performed either ladder drill exercises—emphasizing rapid foot movement, coordination, and directional changes—or plyometric training, focusing on developing explosive power through hurdle jumps. Each session concluded with a five-minute cool-down consisting of active recovery activities and stretching exercises.

Training intensity progressively increased each week, following the principles of overload and individualization. The first two weeks focused on movement familiarization and technique refinement with moderate intensity. By weeks three and four, the complexity and intensity of drills increased, incorporating multi-directional movements and speed variations. Weeks five and six emphasized maximal effort, speed, and quick transitions. A tapering period was implemented in week four to facilitate recovery before the final phase of the intervention.

Table 2. The two-way factorial ANOVA design.

BMI (B)	Agility (A)	
	Snake Jump A1 (ladder drill)	Hurdle Jumps A2 (Plyometric Training)
High (B1)	A1B1	A2B1
Low (B2)	A1B2	A2B2
Total	A1	A2

Notes: BMI = Body Mass Index, SJ = snake jump, LD = ladder drill, HJ = hurdle jumps, PT = plyometric training, AF = agility

Measurements and Data Collection

We used a digital scale (OMRON Model HN-289, Japan) to measure weight in kilograms and a portable Seca® stadiometer (North America) the Body Mass Index (BMI) may be calculated by measuring the height in meters. BMI was determined using the conventional formula, which is the product of the square of the height in meters and the weight in kilograms.

Agility performance was assessed using the Illinois Agility Test, administered under standardized conditions.

The test was conducted on a marked futsal court with cones placed at precise intervals. Participants completed three trials with a two-minute rest period between each trial. The fastest recorded time was used for statistical analysis. A certified coach supervised the test to ensure proper execution and minimize variability in results.

Statistical Analysis

Descriptive statistics were calculated to summarize participant characteristics and training effects. The Shapiro-Wilk test was applied to assess the normality of the data distribution, and Levene's test was used to verify the homogeneity of variances. A two-way ANOVA was conducted to examine the main and interaction effects of training modality and BMI on agility performance. Post hoc pairwise comparisons were performed using the Tukey test ($p < 0.05$). The magnitude of observed effects was quantified using partial eta squared (η^2p). Additionally, 95% confidence intervals were reported to strengthen the interpretation of the results. All statistical analyses were performed using IBM SPSS Statistics Version 25, with the significance level set at $p < 0.05$.

Results

According to the research, the average and standard deviation of agility before and after the test showed increasing trends as follows: A1B1 (18.32 ± 0.343 to 16.02 ± 0.359), A1B2 (18.26 ± 0.202 to 17.28 ± 0.263), A2B1 (18.59 ± 0.21 to 17.32 ± 0.248), and A2B2 (18.16 ± 0.416 to 16.74 ± 0.268). The initial evaluation revealed that group A1B2 had the highest percentage at 10.85% (1.98). The A2B2 group subsequently had a 7.83% increase (1.42) and secured the second position. Subsequently, the A1B1 group exhibited the third highest proportion at 7.09% (1.3). The A2B1 group exhibited a 6.82% growth (1.26), securing fourth place. For additional information, please consult Table 3.

According to the research, the results showed that groups A1 and A2 had average agility scores of 16.66 ± 0.49 and 17.03 ± 0.39 , respectively. The averages for group B1 were 17.18 ± 0.34 and for group B2, 16.51 ± 0.35 . Group

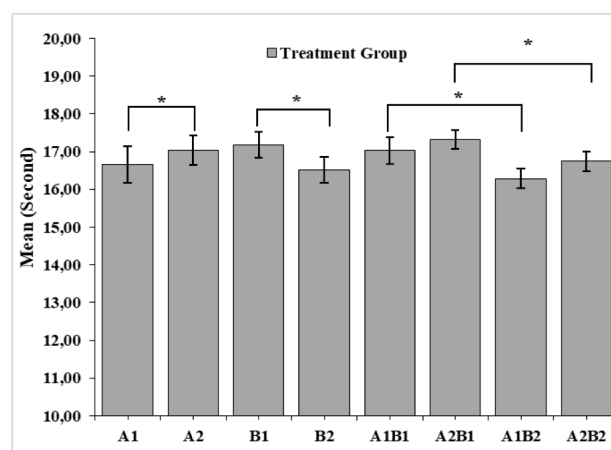


Fig. 2. A comparison was made between the average agility of each treatment group (* $p < 0.05$). For agility, the data is shown with standard deviation and mean values

Table 3. The average differences, standard deviations, and percentage enhancements in pre-test and post-test agility scores for each treatment group

AFE Method	AFE BMI level of each group (n=5)	Pre-Test	Post Test	Δ	%
		M $\pm$ SD	M $\pm$ SD		
LD (SJ)	High (A1B1)	18.32 $\pm$ 0.343	16.02 $\pm$ 0.359	1.3	7.09
	Low (A1B2)	18.26 $\pm$ 0.202	17.28 $\pm$ 0.263	1.98	10.85
PT (HJ)	High (A2B1)	18.59 $\pm$ 0.21	17.32 $\pm$ 0.248	1.26	6.82
	Low (A2B2)	18.16 $\pm$ 0.416	16.74 $\pm$ 0.268	1.42	7.83

Note: AFE = agility exercise, BMI = body mass index, SJ = snake jump, LD = ladder drill, HJ = hurdle jumps, PT = plyometric training, Δ = delta

Table 4. The outcomes of the agility for each treatment group

Group	n	Min	Max	M $\pm$ SD
A1	10	16.01	17.34	16.66 $\pm$ 0.49
A2	10	16.52	17.72	17.03 $\pm$ 0.39
B1	10	16.34	17.72	17.18 $\pm$ 0.34
B2	10	16.01	17.18	16.51 $\pm$ 0.35
A1B1	5	16.34	17.34	17.03 $\pm$ 0.36
A2B1	5	17.02	17.72	17.32 $\pm$ 0.25
A1B2	5	16.01	16.72	16.28 $\pm$ 0.26
A2B2	5	16.52	17.18	16.74 $\pm$ 0.27

Note: Agility, as measured in seconds, is the dependent variable. "A1" denotes ladder drills, which include snake leaps, "A2" denotes plyometric training (hurdle jumps), "B1" indicates high BMI, "B2" signifies low BMI, "A1B1" represents ladder drills (snake jumps) with high BMI, "A2B1" pertains to plyometric training (hurdle jumps) with high BMI, "A1B2" describes ladder drills (snake jumps) with low BMI, and "A2B2" relates to plyometric training (hurdle jumps) with low BMI.

A2B1 had an average agility of 17.32 $\pm$ 0.25, while Group A1B1 had 17.03 $\pm$ 0.36. At the same time, A1B2 had a value of 16.28 $\pm$ 0.26, and A2B2 had a value of 16.74 $\pm$ 0.27. According to Table 3, the A1B2 group showed the most notable average increase out of all the treatment groups. Two visual representations of the data are Figure 2 and Table 4. Results from the tests for normalcy and homogeneity are shown in Table 5, demonstrating that all of the data points are consistent and normal ($P > 0.05$). Both the normality and detrended plots are shown in Figure 3.

Table 5. Testing for normality and homogeneity

Normality test			Homogeneity test		
Shapiro-Wilk			Levene's		
Statistic	df	p	df1	df2	P
0.142	20	0.345	3	16	0.926

Note: Data is normally distributed and homogeneous ($P > 0.05$).

Table 6. Two-way factorial ANOVA

Origin	Type III Sum of Squares	df	Mean Square	F	P
Agility Training (A)	0.711	1	0.711	52.249	0.019
BMI (B)	2.198	1	2.198	72.316	0.000
Agility Training (A) * BMI (B)	0.633	1	0.633	6.508	0.000

Note: The dependent variable in this study was agility. Groups A1 and A2 showed a distinct difference ($P < 0.05$) about "agility training (ladder drill and plyometric)", which indicates that it had an impact on agility. The B1 and B2 groups demonstrated a statistically significant difference ($P < 0.05$) in the "BMI" readings. When the "agility training" and "BMI" groups (A and B) interacted, it significantly impacted agility ($P < 0.05$).

In Table 6 below, you can see the outcomes of the two-way ANOVA. The table indicates that there are substantial differences in explosive power between groups A1 and A2 ($P < 0.05$) and B1 and B2 ($P < 0.05$). As seen in Figure 4, there is a substantial interaction between Groups A and B ($P < 0.05$). Next, we used the Tukey test as a follow-up to determine which treatment group improved agility the most.

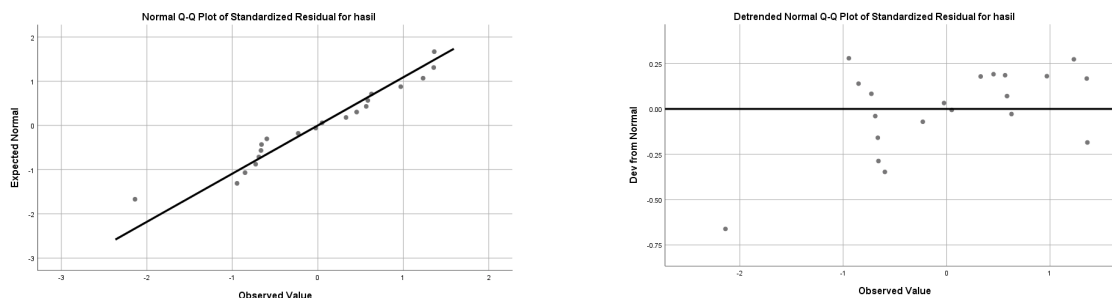


Fig. 3. Normality plot and detrended normality plot graphs

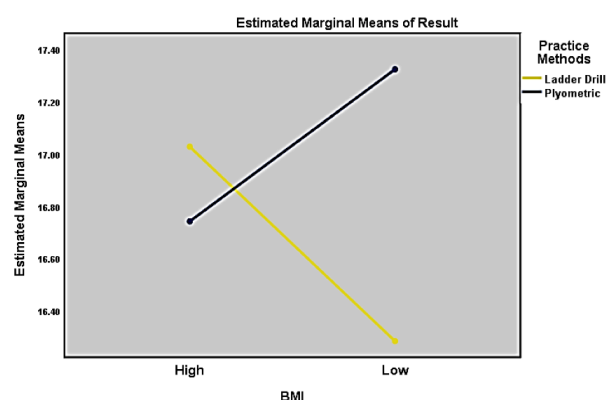


Fig. 4. An examination of the correlation between agility training and BMI

According to Table 7, which is based on Tukey's post hoc analysis, Group A1 improved agility more than Group A2 ($P < 0.05$). For example, consider that 16.66 is often less than 17.03. According to the results, group B1 had a faster speed than group B2 ($P < 0.05$), as shown by an average of $17.72 < 17.18$. Groups A1B1 and A2B1 had substantially different agility test results ($P < 0.05$), with group A1B1 average 17.03 and group A2B1 17.23. Furthermore, when contrasted with the A2B1 group, the A1B1 group had significantly better agility outcomes ($P < 0.05$).

Table 7. Tukey's test

Compare Groups	P	Conclusion
A1 and A2	0.000	Significant
B1 and B2	0.001	Significant
A1B1 and A1B2	0.000	Significant
A2B1 and A2B2	0.003	Significant

Note: The variable that depends on others is agility. The difference is statistically significant ($P < 0.05$).

Discussion

The present study examined the effects of ladder drills and plyometric training on the agility of futsal players while considering the moderating role of BMI. The findings revealed that both training modalities significantly improved agility performance. However, ladder drill training demonstrated superior outcomes to plyometric training across different BMI categories. Furthermore, it was found that BMI influenced the extent of agility improvements, with players possessing a lower BMI showing more significant enhancement in performance.

The greater effectiveness of ladder drill training can be attributed to the specific nature of the exercises involved. Ladder workouts place great emphasis on quick foot movements, exact body control, rhythm, balance, and regular directional changes (Ashar, Setijono, & Mintarto, 2021; Bassa et al., 2024; Sanrijaya, Wirriawan, & Wibowo, 2023; Saini, Dubey, & Vishwakarma, 2025). These characteristics closely mirror the movement needs experienced during futsal matches, where quick, multi-directional footwork is essential (Yiannaki et al., 2020; Belo et al., 2024; Rico-González et al.,

2020). Ladder drills are thought to have generated neuromuscular adaptations using continuous repetition and progression, improving motor unit recruitment, coordination, and reaction speed (Ravi & K, 2024; Neto et al., 2024; James et al., 2021). Players thus grew increasingly skilled at carrying out quick motions, accelerating, decelerating, and changing direction with little loss of speed and balance. Plyometric training enhanced agility, but its emphasis on explosive force and vertical jump performance may not directly correlate with the unique movement patterns necessary in futsal. Plyometric exercises increase muscle strength and reactive force generation, which is beneficial for sports with jumping and sprinting (Gross et al., 2022; Ramirez-Campillo et al., 2023; Matuszczyk et al., 2025). However, in futsal, agility often demands quick, subtle, low-amplitude movements and rapid footwork over short distances, where control and efficiency are prioritized over pure explosive strength (Ari et al., 2024; Lima et al., 2024; Serrano et al., 2020). Thus, whereas plyometric training increased general athleticism, ladder drills seemed more closely suited to the functional agility needs of the sport.

Another key finding was the moderating effect of BMI on agility development. Players with lower BMI demonstrated more noticeable increases in agility after the training sessions. This can be attributed to their reduced mechanical resistance, which facilitates quicker acceleration, sharper directional changes, and smoother transitions during movement. Conversely, individuals with elevated BMI may have increased inertia during rapid directional shifts, necessitating more significant effort to initiate and control their movements (Granero-Gil et al., 2020; Popowczak et al., 2022). Extra body mass could also affect stability and balance during quick movements, hence reducing the general efficacy of agility-focused training (Fauziah et al., 2024; Koltai et al., 2021). Still, it is remarkable that those with greater BMI gained from ladder drills and plyometric exercises, suggesting that organized agility programs are useful for all body types. The degree of improvement, nevertheless, was lower, suggesting that extra interventions targeting body composition, strength-to-weight ratio, and mobility could enhance the effectiveness of agility training for this group. Maximizing the agility potential of every athlete may call for tailored training prescriptions considering BMI and other relevant physical characteristics.

Coaches, trainers, and sports scientists working in futsal and related sports will find these results practical. Agility training programs should prioritize exercises that closely simulate sport-specific movement patterns, such as ladder drills, to achieve more meaningful improvements in player performance. Athlete screening should also include body composition assessments to tailor training loads, progression programs, and other therapies depending on individual needs. From a wider angle, this study's findings underline the need to use a whole strategy for athletic growth. Agility is influenced by technical drills or muscular strength and a complex interaction of neuromuscular synchronization, biomechanical efficiency, body composition, and physical fitness. Acknowledging and handling these elements will help to provide more thorough and helpful training results.

Moreover, this study emphasizes the possibility of future research to find the best combinations of training strategies suited to athletes with different physical traits. Investigating integrated programs that blend agility drills,

plyometric exercises, strength training, and conditioning in personalized formats could lead to even more significant performance gains. Extending the duration of interventions and including varied training intensities may yield valuable insights into the long-term development and preservation of agility during an athlete's career.

The findings emphasize the need for strategically planned, customized training techniques that consider significant physical aspects, including BMI and support the basic relevance of agility in futsal. Ladder drill training proved a very efficient approach to increasing agility across player profiles, with reasonable, sport-specific advantages.

Conclusion

The study verified that ladder drills and plyometric training improve futsal players' agility. Ladder drill training was more successful than plyometric workouts in improving agility regardless of the athletes' BMI. The results also revealed that those with lower BMI had more significant agility improvements than their higher-BMI counterparts, stressing the importance of body composition in training response.

The findings highlight the value of ladder drills in agility-focused conditioning programs, mainly due to their emphasis on quick foot movements, coordination, and dynamic balance all of which are essential in futsal. The effect of BMI on agility results underlines the need to customize training courses to fit individual physical traits. Programs tailored for BMI differences should improve agility development and offer fair progress among athletes with different body types. Training tailored to BMI differences might improve agility growth and offer fair advancement among athletes with different body types.

Future studies should evaluate additional physical characteristics such as muscular strength, power, flexibility, and cardiovascular endurance to determine how they interact with agility training responses. Long-term intervention studies are also recommended to analyze the sustainability of training benefits and discover the most effective combinations of approaches across different age groups, competitive levels, and physical profiles. Such studies will help to create more thorough, customized training courses to maximize futsal and related sports.

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Conflict of Interest

All authors assert the absence of any conflict of interest.

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Вплив застосування вправ із використанням координаційної драбини та пліометричного тренування на спритність футзалістів з урахуванням індексу маси тіла

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 10 с., 7 табл., 4 рис., 64 джерела.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу застосування вправ із використанням координаційної драбини та пліометричного тренування на спритність футзалістів, враховуючи їх класифікацію за індексом маси тіла (ІМТ).

Матеріали та методи. У дослідженні взяли участь двадцять чоловіків-футзалістів з академії “Vamos Academy Padang”, яких було розділено на дві групи за індексом маси тіла (групи із високим ІМТ та низьким ІМТ). Кожна група за ІМТ була розподілена відповідно до типу інтервенційної методики, що передбачала проведення комплексу вправ із використанням координаційної драбини та пліометричних тренувань протягом шести тижнів. На етапах перед- та постінтервенційної програми було проведено оцінку показників спритності за допомогою Іллінойського тесту на спритність. Аналіз даних включав парні та незалежні t-критерії, а також двофакторний дисперсійний аналіз з метою оцінки групових відмінностей.

Результати. Обидві тренувальні інтервенції сприяли значному покращенню показників спритності порівняно з пліометричним тренуванням за всіма класифікаціями ІМТ. Крім того, спортсмени з низьким ІМТ продемонстрували більш виражені позитивні результати, ніж спортсмени з високим ІМТ. Встановлено значну взаємодію між типом тренування та класифікацією ІМТ, що свідчить про вплив композиції тіла на ефективність програм з тренування спритності.

Висновки. Тренування із використанням координаційної драбини виявилось ефективнішим за пліометричне тренування з точки зору підвищення спритності у футзалістів, особливо тих, хто має нижчий показник ІМТ. Отримані результати вказують на необхідність врахування тренерами ІМТ спортсменів при розробленні програм з тренування спритності задля оптимізації показників результативності.

Ключові слова: спритність, вправи із використанням координаційної драбини, пліометричне тренування, індекс маси тіла, координація рухів.

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Psychotype and Thinking Style as Predictors of Success in Esports

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Abstract

Objectives. This study aimed to identify the cluster structure of esports athletes' psychological profiles based on psychotype, thinking style, age, and gaming experience, with the objective of applying the findings to training programs and psychological support.

Materials and methods. The study involved 53 esports players aged 18 to 27. Data were collected using psychodiagnostic tools: an adapted MBTI model, the Eysenck Personality Inventory (EPI), subjective scales for assessing emotional stability, and a thinking style questionnaire. Pearson's chi-square (χ^2) test for independent samples was used to compare observed and expected frequencies. Cluster analysis was conducted using the Statistica "Data Mining" module (k-means method, Euclidean distance, initial centers with maximum distance, and 10-fold cross-validation). ANOVA was applied to assess statistically significant differences in means within and between clusters. Bonferroni's post hoc test was used to determine which cluster pairs differed substantially. Hypotheses were tested at a significance level of $\alpha = 0.05$.

Results. Three clusters were identified based on psychotype: "Socially Adaptive" (32.1 %), "Introverted Analysts" (45.3 %), and "Active Extraverts" (22.6 %). Participants in the "Active Extraverts" cluster were older and had significantly more gaming experience. Two clusters emerged based on thinking style: "Structured Thinkers" (60.4 %) and "Adaptive Thinkers" (39.6 %), which differed considerably in their preference for clear instructions and planning strategies. The majority of players (over 85 %) demonstrated a logical or analytic-intuitive thinking style. A marked relationship was found between thinking style cluster affiliation and the overall score on the thinking style scale ($r_{pb} = 0.672$; $p < 0.0001$), confirming the validity of the clustering. The findings align with international data on cognitive flexibility, adaptability, and the role of mental coaching in esports.

Conclusions. The study proves that cluster analysis enables the typologization of esports athletes based on cognitive-behavioral profiles, thereby providing a foundation for the development of individualized training and psychological coaching programs.

Keywords: esports, psychotype, thinking style, cognitive profile, cluster analysis, psychological support.

Introduction

In modern esports, not only the players' technical skills play a significant role, but also their cognitive and psychological traits, which influence performance, stress resilience, and long-term professional engagement. Particular attention should be paid to the study of psychotypological characteristics and thinking styles, as well as their evolution with age and gaming experience. Despite the growing interest

in esports as a professional field, there is a lack of systematic research focused on psychological player profiles using advanced statistical methods such as clustering (Martínez, Nicolas, et al., 2021; Torres Rodríguez, Griffiths, et al., 2018).

In Ukrainian academic discourse, there is a distinct shortage of in-depth empirical studies exploring esports athletes' psychological profiles through a comprehensive analysis of psychotype and cognitive style. Understanding these traits is essential for developing individualized training programs, preventing emotional burnout, assigning team roles, and increasing resistance to tournament stress (Bonnar, Gradisar, et al., 2024). It is especially important to track how these psychological and cognitive characteristics change based on the athlete's age and experience.

International research increasingly focuses on mental and cognitive mechanisms associated with success in esports. Himmelstein, Liu, and Shapiro (2017), emphasized the importance of mental skills—such as focus, emotional regulation, and self-control—for high-level performance. Pedraza-Ramirez et al. (2020) highlighted the lack of structured psychological research in esports and outlined priority areas, including cognitive control, temperament, and personality traits. Trotter et al. (2021) drew particular attention to the role of psychological support for players, justifying the need for applied sport psychology in esports for both individual development and team stability. Kegelaers et al. (2024) emphasize the importance of developing individualized mental health strategies that account for the cognitive and personality differences among players. In turn, Poulus et al. (2023) demonstrated that an esports-adapted cognitive-behavioral training program (E-CET) enhances stress resilience, subjective performance, and players' mental well-being. The study by Sanz-Fernández et al. (2025), conducted in traditional sports, shows the effectiveness of clustering and data mining methods for identifying psychotypological profiles, thus providing a solid foundation for implementing similar models in esports. Jang, Byon, et al. (2021) employed cluster analysis to segment players based on their level of engagement in esports. The 2025 study on FIFA player training indicates improvements in cognitive abilities (Imanian, Khatibi, et al., 2025).

Several Ukrainian studies also confirm the relevance of profiling esports players. In particular, the works of Shynkaruk et al. (2023, 2024) highlight the importance of psychological training, strategies to minimize tilt, and the adaptation of training programs to players' personality traits. Furthermore, Smith et al. (2019, 2022) draw attention to mental health risks among esports athletes, while Trotter et al. (2021,) emphasize the importance of psychological skills and social support as key success factors in competitive settings.

However, despite existing reviews and practical initiatives, there remains a lack of comprehensive empirical research that integrates psychotype, thinking style, gaming experience, and age using statistical clustering methods. This combination constitutes the scientific novelty of the present study, which aims to typologize the cognitive-behavioral profiles of esports athletes to enable more effective individualization of their preparation programs.

Despite the availability of general reviews, there is still a lack of studies combining cluster analysis with individual psychotypological traits of esports athletes—this constitutes the scientific novelty of this work.

The purpose of the study was to identify the cluster structure of esports athletes' psychological profiles based on psychotype, thinking style, age, and gaming experience, with the aim of applying the findings to training programs and psychological support.

Materials and Methods

Study participants

A total of 53 respondents (men and women aged 18–30) participated, all of whom had experience in official or semi-professional tournaments in such disciplines as Counter-

Strike 2, Dota 2, Valorant, and League of Legends. The age range was 19–26 years, and gaming experience ranged from 3 to 10 years.

Study Organization

The research was conducted in 2025 among participants from the esports environment, particularly players.

This study employed a combination of empirical, mathematical-statistical, and psychodiagnostic methods, enabling an in-depth analysis of the psychological characteristics of esports athletes.

Surveying was used to collect primary data on age, experience, roles within the esports ecosystem, preferred disciplines, and self-assessment of psychological traits. A customized questionnaire adapted to the context of esports was utilized. Surveys and psychometric testing were conducted remotely and anonymously using a secured Google Forms platform.

Psychodiagnostics were employed to identify personality characteristics (psychotype), including a simplified version of the MBTI (Myers-Briggs Type Indicator) adapted for self-assessment, the EPI (Eysenck Personality Inventory) for evaluating extraversion/introversion and neuroticism, and subjective self-assessment scales for measuring emotional stability, reflection, and self-control. To examine thinking styles, a questionnaire was used that assesses the dominant mode of information processing (logical, analytical-intuitive, or intuitive). The questionnaire consisted of 25 closed and semi-open questions grouped into five thematic blocks: general information, psychotype, thinking style, temperament and stress response, and self-assessed emotional stability. The methodology was piloted on a sample of 30 esports athletes during a preliminary study.

Statistical Analysis

Prior to analysis, the normality of the distribution of quantitative data was verified using the Shapiro–Wilk W-test, appropriate given the sample size ($n = 53$). Since the distributions for age and experience did not conform to normality, the central tendency and spread were described using the first and third quartiles (Q1; Q3).

For comparing observed and expected frequencies, Pearson's chi-square test was applied. In the case of categorical data distributions, degrees of freedom (df) were calculated as the product of the number of categories minus one and the number of rows minus one (for contingency tables), or the number of categories minus one (for one-dimensional distributions) (Shynkaruk, Byshevets, et al. 2025).

Cluster analysis (k-means) was used to identify latent groups of esports athletes based on psychological characteristics. Cluster analysis, as an exploratory method, groups similar cases based on their shared characteristics without prior assumptions regarding the number or structure of the groups. To identify natural clusters in the data, the Data Mining module of Statistica software was used, specifically the k-means method with Euclidean distance as the metric and initial centers selected according to the maximum initial distance criterion.

To assess the stability of the results and minimize the risk of overfitting, 10-fold cross-validation was applied. In

this approach, the dataset was randomly divided into 10 subsets with iterative training and testing of the clustering model.

The optimal number of clusters was determined automatically by the built-in mechanism of Statistica based on the training error minimization criterion.

As a result:

- Based on a set of psychological characteristics related to psychotype, three clusters were identified (training error: 0.9245);
- According to thinking style indicators, two clusters were formed (training error: 0.9129).

Pearson's chi-square test for independent samples was used to analyze independent distributions of qualitative variables (psychotype, community role, behavioral style, etc.).

Analysis of variance (ANOVA) was applied to determine statistically significant differences in mean values within and between clusters.

The F-test (Fisher's criterion) was used in ANOVA to determine whether statistically significant differences existed between mean values of two or more groups. This confirmed that the identified clusters differed significantly in terms of quantitative variables (experience, age). Degrees of freedom df1 (between groups) and df2 (within groups) were reported.

A scoring distribution method was also used as a confirmatory approach to categorize respondents based on total points.

Point-biserial correlation. To quantify the relationship between a dichotomous variable (cluster membership) and a continuous variable (e.g., scores, experience), point-biserial correlation was applied. This coefficient, a special case of Pearson's correlation, measures the strength and direction of association between group membership and scale values. In cases with more than two clusters, one-way ANOVA was used to identify statistically significant mean differences across clusters.

The Bonferroni post hoc test was employed to determine which cluster pairs differed significantly.

All hypotheses were tested at a significance level of $\alpha = 0.05$. Calculations were conducted using Statistica 10 (StatSoft, USA).

Data analysis was performed using the Statistica 10.0 software package (StatSoft, USA), in accordance with ethical standards of voluntary participation and confidentiality.

Results

The respondents' median age was 21.0 years ($Q1 = 19.0$; $Q3 = 22.0$), and their esports experience was 5.0 years ($Q1 = 3.0$; $Q3 = 8.0$), indicating that most participants entered the esports scene during adolescence.

A total of 53 individuals participated in the study, including players, coaches, and esports specialists. The study aimed to determine how different emotional states influence individual and team performance during preparation and competition across various esports disciplines.

An analysis of respondents' roles within the esports community showed that each participant typically identified with at least two roles (53 respondents gave 103 responses). Statistically significant preference was observed for the

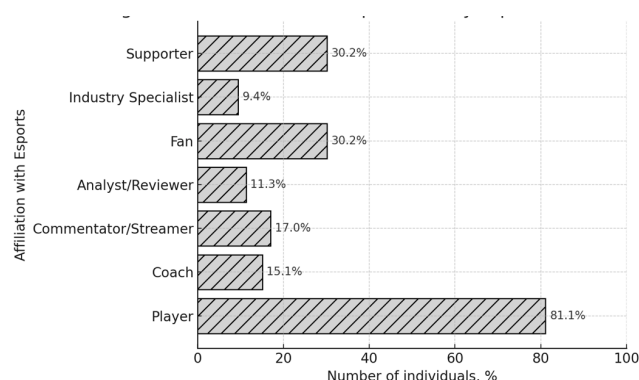


Fig. 1. Distribution of respondents by esports affiliation (n = 53)

player role, with 81.1 % identifying as players ($\chi^2 = 20.547$; $df = 1$; $p < 0.05$) (See Figure 1).

Respondents' answers about preferred esports disciplines varied greatly; however, 37.7% indicated either Counter-Strike 2 or Dota 2 as their main discipline.

To assess strengths and weaknesses in respondents' personalities, we applied a psychological assessment based on the MBTI model.

When analyzing psychotype data (extraversion vs. introversion), it was found that all parameters were statistically evenly distributed ($p > 0.05$), indicating no dominant tendency in the sample. This included comfort working in a team ($\chi^2 = 0.019$; $df = 1$; $p = 0.8907$), preferred rest style (alone vs. in company) ($\chi^2 = 3.189$; $df = 1$; $p = 0.0742$), reaction to social interaction (energized vs. fatigued) ($\chi^2 = 2.283$; $df = 1$; $p = 0.1308$), decision-making style (reflective vs. impulsive) ($\chi^2 = 3.189$; $df = 1$; $p = 0.0742$), and ease of making new acquaintances (easily vs. context-dependent or difficult) ($\chi^2 = 3.189$; $df = 1$; $p = 0.0742$).

Cluster analysis showed that based on age ($F = 7.331$; $df1 = 2$; $df2 = 50$; $p = 0.0016$), experience ($F = 5.133$; $df1 = 2$; $df2 = 50$; $p = 0.0094$), and other psychological characteristics, the respondents could be grouped into three distinct clusters (See Table 1).

Cluster 1: "Socially Adaptive" (32.1%) – Respondents with a mean age of 19.1 years and 4.9 years of esports experience. They prefer group work, feel energized after social interaction, make considered decisions, enjoy social or event-based leisure, and form new connections situationally.

Cluster 2: "Introverted Analysts" (45.3%) – Mean age 22.1 years, 5.2 years of experience. Prefer solitude, feel fatigued after socializing, are reflective, prefer quiet rest, and tend to form connections based on context.

Cluster 3: "Active Extraverts" (22.6%) – Mean age 25.9 years, 9.8 years of experience. Enjoy teamwork, feel energized by social contact, act enthusiastically and impulsively, prefer social leisure, and make friends easily.

A clear link was established between psychotype, age, and experience. Members of Cluster 3 ("Active Extraverts") were statistically significantly older (25.9 years) and had longer gaming experience (9.8 years) compared to other groups.

This suggests that extraverted traits such as ease of forming connections and gaining energy from social interactions may contribute to greater longevity in esports careers.

Table 1. Characteristics of Esports Players by Cluster (n = 53)

Cluster	% of Sample	Mean Age (years)		Mean Experience (years)		Criterion	Chi-square / p value
		M	SD	M	SD		
Psychotype							
1. Socially Adaptive	32.1	19.1	2.8	4.9	2.6	Comfortable working in a group	$\chi^2=29.109$; df=2; p<0.0001
						Effect of social interaction	$\chi^2=23.289$; df=2; p<0.0001
2. Introverted Analysts	45.3	22.1	4.9	5.2	4.3	Thoughtful action	$\chi^2=12.792$; df=2; p=0.0017
						Preferred rest	$\chi^2=16.260$; df=2; p=0.0003
3. Active Extraverts	22.6	25.9	6.4	9.8	6.7	Ability to socialize	$\chi^2=27.894$; df=4; p<0.0001
Thinking Style							
1. Structured Thinkers	60.4	20.9	3.9	4.7	3.4	Reliance on logic	$\chi^2=0.579$; df=1; p=0.4469
						Trust in facts	$\chi^2=0.025$; df=1; p=0.8737
						Need for instructions	$\chi^2=35.031$; df=1; p<0.0001
2. Adaptive Thinkers	39.6	23.7	6.7	8.3	5.9	Adherence to plan	$\chi^2=23.049$; df=1; p<0.0001
						Error analysis	$\chi^2=2.068$; df=1; p=0.1504

Note. SD = Standard Deviation; M = Mean; df = degrees of freedom; Chi-square = chi-square test; p value = level of statistical significance (value “ $p < 0.0001$ ” is shown as “ <0.0001 ”; in other cases – rounded to four decimal places)

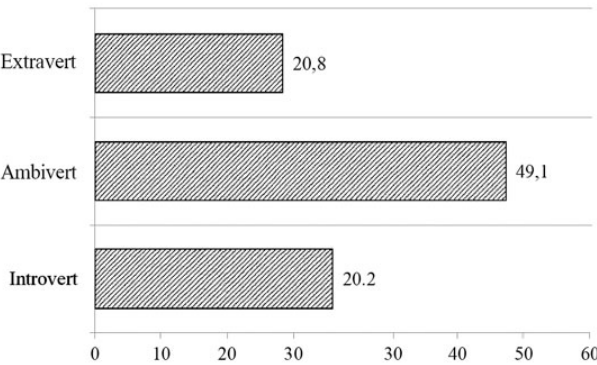


Fig. 2. Distribution of respondents by psychotype (n = 53)

Overall, cluster distribution among respondents was statistically even ($\chi^2=0.154$; df=2; $p=0.9259$).

Additionally, using a scoring system for extraversion-related responses (1 point per extravert trait; total range 0–5), respondents were categorized as follows: 0–1 points = introvert, 2–3 = ambivert, 4–5 = extravert. Results showed that 49.1% were ambiverts, 30.2% introverts, and 20.8% extraverts (See Figure 2).

To verify whether the clusters aligned with extraversion-introversion scores, a one-way ANOVA was conducted. Statistically significant differences were found between clusters in terms of extraversion scores ($F=66.07$; $df_1=2$; $df_2=50$; $p<0.0001$). A post hoc Bonferroni test confirmed significant differences between all cluster pairs ($p<0.0001$), indicating clear differentiation among the groups.

The application of cluster analysis allowed us to identify three distinct psychotypological groups among esports athletes: “Socially Adaptive,” “Introverted Analysts,” and “Active Extraverts.” An intriguing finding is that the

“Active Extraverts” demonstrated significantly more gaming experience and were older on average. This may indicate that certain extraverted traits—such as ease of communication, impulsive and energetic actions, and deriving positive emotions from social interaction—are adaptive for a long-term career or extended presence in the esports environment, where teamwork and networking play a crucial role.

The consistency between the identified clusters and the scoring on the extraversion/introversion scale, as confirmed by one-way ANOVA ($F = 66.07$; $df_1 = 2$; $df_2 = 50$; $p < 0.0001$) and Bonferroni post hoc comparisons ($p < 0.0001$ for all pairwise comparisons), strengthens the reliability and validity of the psychotypological findings. This indicates that despite potential variability across specific traits, the clusters collectively form well-defined psychological profiles aligned with theoretical constructs of extraversion/introversion and merit further investigation.

In examining the thinking style of the respondents, we found that based on two criteria—namely, the tendency to rely on logic and facts when making decisions (as opposed to intuitive actions), and trust in analysis and evidence (compared to internal premonitions)—participants statistically significantly preferred a logical approach (in both cases, $\chi^2 = 6.811$; $df = 1$; $p = 0.0091$).

In contrast, for the responses to the questions “What suits you better?” (clear instructions / room for interpretation) and “Planning approach” (clear plan / spontaneity), the distribution of respondents did not differ significantly from uniformity ($\chi^2 = 0.472$; $df = 1$; $p = 0.4922$). However, esports athletes were statistically significantly more likely ($\chi^2 = 31.717$; $df = 1$; $p < 0.05$) to analyze their mistakes in order to avoid them in the future, rather than ignore them and move on.

Unlike the previous psychotype analysis, clustering based on thinking style criteria revealed two respondent groups that were less sharply defined in their characteristics.

Statistically significant differences between these clusters were observed only in the following indicators: gaming experience ($F = 7.798$; $df_1 = 1$; $df_2 = 51$; $p = 0.0073$), the need for clear instructions ($p < 0.05$), and planning approach ($p < 0.05$) (See Table 1).

Cluster 1: “Structured Thinkers” (60.4%). This group consisted of respondents with a mean age of 20.9 years and an average gaming experience of 4.7 years. They are characterized by a tendency to rely on logic and facts, trust in analysis and evidence, and a consistent practice of analyzing mistakes to prevent them in the future (these traits are shared across both clusters). At the same time, representatives of this cluster require clear instructions and follow a structured plan.

Cluster 2: “Adaptive Thinkers” (39.6%). This cluster included respondents with an average age of 23.7 years and a significantly greater gaming experience—8.3 years. Like the members of the first cluster, they rely on logic and facts, trust analysis and evidence, and analyze mistakes to avoid repeating them. A distinguishing feature of this group is their preference for interpretative freedom and their tendency to act spontaneously or creatively during planning.

A summary of the characteristics of the esports athlete clusters based on psychotype and thinking style is presented in Table 1.

Similar to the approach used for identifying the dominant psychotype, to determine the prevailing style of information processing, each response corresponding to the “logical” style was scored as 1 point. The total score ranged from 0 to 5 and allowed respondents to be categorized into three thinking styles: 0–1 point — intuitive; 2–3 points — analytical-intuitive; 4–5 points — logical. It was found that 45.3% of respondents demonstrate a logical thinking style, 41.5% — analytical-intuitive, and only 13.2% — intuitive (See Figure 3).

Since the point-based distribution of respondents by thinking style revealed three categories (logical, analytical-intuitive, and intuitive), whereas the cluster analysis identified two groups (“Structured Thinkers” and “Adaptive Thinkers”), an additional analysis was conducted to examine the relationship between these two approaches. The results of the point-biserial correlation calculation showed a statistically significant association between cluster

membership and the total score on the thinking style scale ($r_b = 0.672$; $t = 6.472$; $p < 0.0001$). This indicates that, despite the different number of identified categories, the clustering reflects substantial differences in cognitive profiles that are also measured by the point-based scale. Therefore, it can be concluded that the two clusters are clearly distinguishable based on the point-based measure, while the point-based distribution provides a more detailed classification (three categories).

The analysis of thinking styles among esports players revealed a complex picture of their cognitive processes. The score-based distribution showed a dominance of logical (45.3%) and analytical-intuitive (41.5%) thinking styles, with only a small proportion displaying an intuitive style (13.2%). This suggests that success in esports likely requires a high capacity for rational analysis, strategic planning, and processing large amounts of information.

Thus, the majority of esports athletes (over 85%) tend to exhibit either logical or balanced (analytical-intuitive) thinking styles. Pure intuitives represent a minority, which may indicate the importance of logic and analytical reasoning for success in esports—an environment where rapid data processing, situation assessment, and rational decision-making are essential.

In contrast, the exploratory cluster analysis, which empirically identified groups based on a combination of characteristics, revealed two distinct cognitive profiles: “Structured Thinkers” (60.4%) and “Adaptive Thinkers” (39.6%). Notably, these clusters differed statistically not in terms of basic logical or intuitive tendencies (as might be expected from direct correspondence to score-based categories), but in their need for clear instructions and planning approaches. “Structured Thinkers” showed greater dependence on external guidelines and clear action plans. This profile may be typical for players still actively mastering game mechanics and tactics, or for those who prefer relying on proven strategies.

In contrast, “Adaptive Thinkers,” representing the minority, had significantly more gaming experience ($F = 7.798$; $df_1 = 1$; $df_2 = 51$; $p = 0.0073$) (8.3 years compared to 4.7 years for “Structured Thinkers”). This greater experience likely correlates with their lower reliance on detailed instructions and rigid planning. The findings suggest that they have developed cognitive flexibility and the ability to effectively adapt in dynamic and unpredictable gaming situations. Their experience likely allows them to rely on intuition and rapid decision-making beyond pre-planned strategies, enabling room for interpretation and spontaneous or creative actions.

Thus, the results highlight that while logical and analytical approaches dominate in esports, players are differentiated by the degree to which they rely on structure versus adaptability. Specifically, greater experience is associated with the development of a more adaptive thinking style, characterized by less need for instruction and greater inclination toward flexibility and creativity during gameplay.

It is worth noting that the relationship between empirically identified clusters and the a priori defined score-based categories is a key aspect of our research. For both psychotype and thinking style, the score-based approach does not contradict the cluster analysis results, confirming the validity of both methods in the context of esports athlete

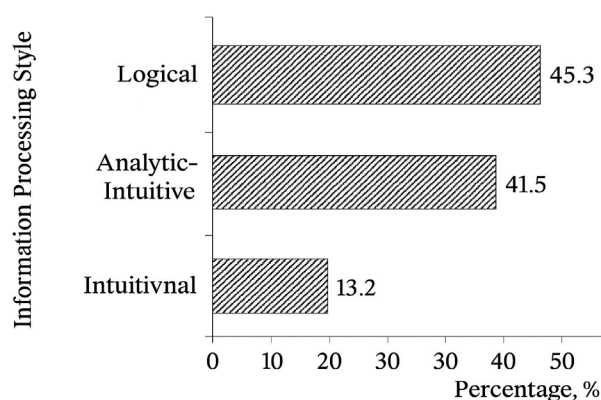


Fig. 3. Distribution of respondents by information processing style ($n = 53$)

profiling. Moreover, in the case of thinking style, the score-based classification provided three categories (logical, analytical-intuitive, intuitive), offering more detailed differentiation than the two clusters. This suggests that the two approaches complement each other—providing both generalized profiles (clusters) and finer-grained distinctions (score-based categories)—which are essential for a comprehensive understanding of esports athletes' cognitive characteristics.

Discussion

The use of cluster analysis made it possible to identify three psychotypological groups ("Socially Adaptive", "Introverted Analysts", and "Active Extraverts") and two thinking styles ("Structured Thinkers" and "Adaptive Thinkers"), which statistically differ in age, experience, and a range of psychological characteristics. This confirms the integrative nature of psychotype and cognitive style in shaping esports players' competitive success. Such an approach allows psychotype and thinking style to be viewed not as isolated variables, but as interrelated behavioral-cognitive profiles that evolve with experience.

The obtained results are consistent with the study by Martinent et al. (2013), in which different affective states of athletes before competitions were identified through cluster analysis. Similar to their findings, we identified clusters with pronounced extraversion traits associated with longer experience in esports, higher social engagement, and a greater ability to adapt quickly in competitive environments.

Our data also complement the results of Torres-Rodríguez et al. (2018), who identified groups of gamers with varying levels of emotional stability and anxiety. However, unlike their clinically oriented approach, our study focuses on the resource-based components of personality—such as decision-making style, energy balance in social interaction, and preferences in cognitive information processing.

Particularly noteworthy is the discovered relationship between respondents' experience and their thinking style: members of the "Adaptive Thinkers" cluster had significantly more gaming experience compared to the "Structured Thinkers" (8.3 vs. 4.7 years). This aligns with the hypothesis by Domínguez-González et al. (2024) suggesting that greater gaming experience correlates with the development of flexible decision-making strategies and a preference for creative thinking over formal instruction. Similar conclusions were also drawn in the work of Martínez-Gallego et al. (2021), which found that athletes with a higher number of matches played exhibit reduced reliance on external structures of control.

He novelty of this study lies in the comprehensive integration of cluster analysis with a scoring-based approach to verify and refine typologies. This methodology enabled the validation of identified clusters through independent methods—particularly the alignment between the quantitative assessment of extraversion and its cluster-based categorization. This indicates a high degree of consistency between empirical observations and psychometric scales, which is rarely achieved in previous studies.

Moreover, our results are the first to provide a detailed account of esports athletes' cognitive-psychological profiles not only by individual parameters but through their complex

constellation. This can be used for the individualization of training processes, mental coaching, and team building. Such findings hold practical value for professionals in esports psychology, coaches, and performance analysts.

Considering the identified clusters of psychotypes and thinking styles, it is advisable to implement individualized training and mental programs tailored to the characteristics of each group. For example:

"Structured Thinkers" require clearly defined goals, step-by-step strategies, and systematic feedback. Scenario-based analysis and pattern-based training would be effective for them.

"Adaptive Thinkers", on the other hand, may achieve better results under dynamic training conditions that involve creativity, improvisation, and decision-making under uncertainty.

Work with "Active Extraverts" should focus on developing resilience under conditions of team responsibility, while "Introverted Analysts" should be supported in building communication skills, reducing anxiety, and enhancing emotional regulation during competitions.

The findings complement current international research on psychological support and cognitive profiling in esports athletes. For instance, Kegelaers et al. (2024) emphasize the importance of mental health in esports and the need to consider individual differences in approaches to psychological support. This aligns with our identification of two thinking styles—"structured" and "adaptive"—which may require fundamentally different mental coaching strategies.

Poulus et al. (2023) demonstrated the effectiveness of adapted cognitive-behavioral training (E-CET), aimed at enhancing resilience and subjective effectiveness in esports players. Our results highlight the need for similar individualized training that takes into account players' cluster affiliation. For example, "active extraverts" may benefit more from socially oriented strategies, while "introverted analysts" may gain from tools for self-reflection and emotional self-regulation.

The experience of Sanz-Fernández et al. (2025) is also of particular importance - they applied data mining methods to construct psychological profiles of track and field athletes. Their findings confirmed the effectiveness of clustering for athlete typology based on psychophysiological parameters. Our study extends this approach to the field of esports, demonstrating that cognitive profiles and psychotypes, similar to those in traditional sports, can be classified and used as a basis for training design.

Additionally, the study by Zhu et al. (2020) showed that player experience significantly influences team effectiveness through the phenomenon of faultlines, which aligns with the advantages observed in adaptive thinkers who demonstrated longer competitive experience.

Himmelstein et al. (2017) argue that effective adaptation to dynamic game environments largely depends on the cognitive structure of thinking. Their recommendation for structured training programs for beginners is consistent with the characteristics of our "Structured Thinkers" cluster, who had the least gaming experience.

Summarizing the positions of Smith et al. (2022) regarding mental health factors in esports athletes and the conclusions of Trotter et al. (2021) on the role of social support, it can be

argued that the thinking profiles and psychotypes identified in this study have potential applications in the development of national psychological support programs. In particular, taking into account the specific characteristics of each cluster may enhance the effectiveness of mental preparation, reduce the risks of emotional burnout, and support a stable esports career. In the study by De Las Heras et al. (2020), the significance of extraversion was emphasized in the context of esports teams, especially as a factor contributing to career longevity—this aligns with our observation of the “Active Extraverts” cluster, which included the oldest and most experienced players.

Additionally, Potard et al. (2019) identified four types of gamers based on psychotype, confirming the viability of clustering based on personality traits. Vega González Bueso et al. (2020) classified adolescents with internet addiction based on comorbid psychotypes, which parallels our approach to psychological grouping.

On the other hand, the study Timokhov, & Sergeev (2023); Zhang (2002) highlights the weak correlation between thinking style and performance in League of Legends (LoL). Meanwhile, Barnett & Coulson (2021), Poulus et al. (2022), Wang (2025) emphasize the advantages of cognitive flexibility and systematic practice as key predictors of long-term success.

Martončík et al. (2024) applied the deliberate-practice framework to measure predictors of long-term success among CSGO and LoL players, finding that age and non-deliberate engagement, rather than intentional practice, significantly predicted performance. Pishchik et al. (2019) compared cognitive profiles of student esports competitors and nonplayers, discovering that intensive gaming correlates with lower logical and critical thinking abilities. Roose & Doherty's (2024) special issue highlights shifts in esports psychology, emphasizing how evolving mental skills and team dynamics shape performance under competitive pressure. Complementing these findings, a meta-analysis by Pohlmeier et al. (2023) synthesizes evidence showing esports experts outperform amateurs in spatial cognition and attention—but not necessarily other cognitive dimensions—supporting the profile-focused, multidimensional approach we advocate.

Thus, the obtained results not only reinforce previous findings regarding the role of cognitive and personality traits in sports performance, but also offer a new methodological model for their typology to be used in profiling and talent selection in esports.

Conclusions

The conducted study made it possible to identify clearly differentiated cognitive-psychological profiles of esports athletes, confirming the interrelationship between psychotype, thinking style, age, and gaming experience. Three psychotypological clusters were identified (“Socially Adaptive,” “Introverted Analysts,” and “Active Extraverts”), which significantly differ in terms of age, gaming experience, and social interaction. The “Active Extraverts” demonstrated the longest gaming experience, indicating a potential advantage of extraverted characteristics in sustaining long-term participation in esports.

Two thinking styles were also identified (“Structured Thinkers” and “Adaptive Thinkers”), showing statistically

significant differences in gaming experience and problem-solving approaches. “Adaptive Thinkers,” who had longer playing experience, exhibited greater flexibility and the ability to make creative decisions.

The use of cluster analysis combined with a scoring approach confirms the validity and practical relevance of the obtained profiles. This approach enables the more effective design of training and psychological programs that account for the individual characteristics of athletes.

Prospects for Future Research

Promising directions for future research include examining the correlation between the identified psychotypes and thinking styles with specific performance indicators and effectiveness across various esports disciplines.

Limitations

This study has certain limitations: the cross-sectional nature of the research does not allow for clear causal inferences between psychotype, thinking style, and success in esports.

Conflict of Interests

The authors state that there is no conflict of interests.

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Психотип і стиль мислення як предиктори успішності в кіберспорті

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 9 с., 1 табл., 3 рис., 33 джерела.

Мета. Виявити кластерну структуру психологічних профілів кіберспортсменів на основі психотипу, стилю мислення, віку та ігрового досвіду для подальшого використання в тренувальному процесі та психологічної підтримки.

Матеріали і методи. У дослідженні взяли участь 53 кіберспортсмени віком від 18 до 27 років. Для збору даних використано психодіагностичні методики: адаптовану модель MBTI, опитувальник Айзенка (EPI), суб'єктивні шкали оцінки емоційної стійкості, опитувальник стилів мислення. Для порівняння спостережуваних і очікуваних частот використувався критерій Пірсона χ^2 (хі-квадрат) для незалежних вибірок. Кластеризація даних, виконана за допомогою модуля Statistica «Data Mining» (метод k-середніх, евклідова відстань, початкові центри з максимальною початковою відстанню, з використанням 10-кратної крос-валідації). Дисперсійний аналіз (ANOVA) використано для перевірки статистично значущих відмінностей між середніми показниками в межах і між кластерами. Для виявлення, які саме пари кластерів статистично значуще відрізняються, використовувався апостеріорний критерій Бонферроні. Гіпотези перевірено на рівні значущості $\alpha = 0,05$.

Результати. Ідентифіковано три кластери за психотипом: «соціально адаптивні» (32,1 %), «інтроверти-аналітики» (45,3 %) і «активні екстраверти» (22,6 %). Учасники з кластеру «активні екстраверти» виявилися старшими за віком і мали значно більший ігровий досвід. За стилем мислення сформовано два кластери: «структуровані мислителі» (60,4 %) та «адаптивні мислителі» (39,6 %), що статистично відрізнялися за потребою в чітких інструкціях і підходом до планування. Більшість гравців (понад 85 %) схильються до логічного або аналітико-інтуїтивного стилю мислення. Встановлено значущий зв'язок між кластерною приналежністю та бальним показником стилю мислення ($r, b = 0,672$; $p < 0,0001$), що підтверджує валідність кластеризації. Отримані результати узгоджуються з міжнародними даними про когнітивну гнучкість, адаптивність і роль ментального коучингу в кіберспорті.

Висновки. Кластерний аналіз дозволяє типологізувати кіберспортсменів за когнітивно-поведінковими профілями, що створює основу для побудови індивідуалізованих програм підготовки та психологічного тренування.

Ключові слова: кіберспорт, психотип, стиль мислення, когнітивний профіль, кластерний аналіз, психологічна підтримка.

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Training Load, Fatigue, and Anterior Cruciate Ligament Injury Risk in Male Collegiate Handball Players: A Two-Season Prospective Cohort Study

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Abstract

Background. Anterior cruciate ligament (ACL) injuries represent a significant issue in competitive handball, frequently resulting in prolonged absence and diminished athletic performance. Given the sport's high physical demands, particularly at the collegiate level, monitoring training load and fatigue is essential to mitigating injury risk.

Objectives. This study aimed to examine the relationship between training load, markers of fatigue, and ACL injury risk in male collegiate handball players during two competition seasons.

Materials and methods. A prospective cohort study was conducted with 93 male athletes (mean age: 20.8 ± 1.6 years) from 13 collegiate handball teams across two seasons (AY 2022-2024). Training load was tracked using weekly hours, session-RPE, and match exposure. The assessment of fatigue was performed through daily wellness ratings and countermovement jump (CMJ) height decline. ACL injury risk was calculated from a composite score including LESS assessments, limb asymmetry, and fatigue-related performance decline. Logistic regression was used to identify predictors of ACL injury, with positional differences examined via ANOVA.

Results. Fatigue score was the only statistically significant predictor of ACL injury ($p = 0.041$). Players reporting higher fatigue levels and categorized within the high training load group exhibited the greatest ACL risk. Right and Centre Backs experienced greater training demands and fatigue accumulation compared to Left Backs.

Conclusions. The findings indicate that persistent fatigue, more than training volume alone, significantly predicts ACL injury risk in collegiate handball players. Integrating regular fatigue monitoring and individualized load management into training programs may reduce injury rates and improve athlete longevity.

Keywords: ACL injury, training load, fatigue monitoring, injury prevention, neuromuscular screening, handball sports performance.

Introduction

Handball is a tremendously intense, contact sport that involves sudden changes in direction, jumping, and almost constant physical contact (Laver et al., 2018). These high-speed movements exert a great amount of force on the lower limbs, especially upon the knee joint, creating a higher risk of anterior cruciate ligament (ACL) injuries for the players (Di Paolo et al., 2021). (Setuain et al. 2018) state that epidemiological studies show that ACL injuries rank among the most common and impede players from competing for a longer duration. In some instances, such injuries may lead to permanent dysfunction (Rector et al., 2019). Therefore,

analyzing the factors associated with ACL injuries, such as training load and fatigue, will assist in formulating preventive measures for this population (Monajati, 2017).

The literature is witnessing a surge of studies emphasizing the important incidence rates of ACL injuries in the men's professional field handball (Myklebust et al., 2007). For example, in the prospective analysis of the 'ACL registry in German Sports' during seven consecutive seasons, the overall incidence was 0.044 ACL injuries per 1,000 hours of exposure, with the rate being found to be higher in the first league compared to the second league (0.064 vs. 0.031 per 1,000 hours, respectively) (Fünten et al., 2023) (Szymiski et al., 2021). In these injuries, re-ruptures accounted for 46.3%, pointing out the difficulty of establishing an effective rehabilitation and return-to-play protocol. Rehabilitation is vital after an ACL injury since if the rehabilitation is

incomplete, the patient may face a great chance of re-injury and complications to the contralateral knee (Setuain et al., 2018). In order to recommend strategies to prevent injuries in players, a clear understanding of how training load and fatigue affect injury risk is portrayed. Hence, this study investigates the relation among training load, fatigue, and ACL injury risk in male collegiate handball players.

The mechanisms behind ACL injury in handball are multivariate. This entails the usual non-contact situations, which constitute sudden deceleration, pivoting, and landing from jumps (Setuain et al., 2018) (Drole et al., 2023). The process is made worse by muscle fatigue, which diminishes neuromuscular control and joint stability (Nasrabadi & Sadeghi, 2022). Fatigue-related changes in movement, such as increased knee valgus angles with decreased knee flexion while landing, have been previously linked to an increased risk of ACL injuries (Bourne et al., 2019) (Verschuere et al., 2020). Training loads are another major factor in injury risk (Eckard et al., 2018). Injuries due to overuse occur when intensive training is done without adequate rest, thus making them more prone to acute injuries like ACL tears. Oppositely, not training enough causes one to be poorly conditioned, slightly increasing the risk of injury. Hence, it is essential to observe and manage training load to avoid injuries (Zeghari et al., 2019).

While the subject of ACL injuries as a major concern in handball is well recognized, the investigation attempted onto male collegiate athletes has been relatively scant (Drole et al., 2023). Many of the extant studies (Schmidt et al., 2022) examine professional or elite players and fail to consider the specific demands and constraints. While the contribution of training load and fatigue to injury mechanisms is recognized, there are only limited contributions from field data to assess these variables in real-time (Zouhal et al., 2021). The current state of literature truly calls for studies coupling objective assessments of training load and fatigue levels and injury surveillance within male collegiate handball players (Maciel et al., 2022). These investigations could provide valuable insight into modifiable risk factors for ACL injury and pave the way for establishing targeted prevention strategies for this population. Rehabilitation should take place without delay post-ACL injury to allow healing and establish normal functioning, including individual programming focused on specific performance characteristics relevant to handball (Arden et al., 2018).

The study's overarching purpose was to investigate the relationships between training load, fatigue, and ACL injury risk in male collegiate handball players over two competitive seasons. The study aimed to identify potential predictors of ACL injury in male collegiate handball players via a prospective cohort design, utilizing a battery of field-based monitoring tools. The central hypothesis is, broadly speaking, that higher training loads and higher fatigue scores are associated with greater risk for ACL injury. It is expected that ACL injury incidence among players who have sustained a greater amount of training load and used the signs of neuromuscular fatigue as indicators will be higher than that of players showing less fatigue.

Materials and Methods

Study Design

A prospective cohort study was conducted over two consecutive competitive handball seasons (AY 2022–2024) to

examine the associations among training load, fatigue, ACL injury risk, and performance outcomes in collegiate male athletes the athletes. The study followed these guidelines to ensure transparency and reproducibility in observational research.

Participants

Ninety-three male handball players (mean age = 20.8 ± 1.6 years) were recruited from thirteen collegiate teams in the Bengaluru region, with a purposive sample being used. Inclusion criteria included: (1) active roster status along with a minimum of 5 hours of structured training per week, (2) no acute musculoskeletal injury at the time of enrolment, and (3) compliance rate of $\geq 80\%$ with the designed mechanisms to monitor movements in a field-based handball context. Players were categorized based on tactical position into Right Back, Left Back, and Centre Back to allow for the analysis of position-specific risk exposure.

Measures and Instruments

Training load was measured utilizing internal and external indicators: session-RPE (when indicated the Borg CR-10 scale), weekly training hours (tracked by coaching staff) and playing exposure. Fatigue was assessed using two methods: daily self-reported wellness (10-point scale) scores, and performance measures, specifically countermovement jump (CMJ) height decrements of $\geq 10\%$ from baseline. The risk of an ACL injury was assessed using a composite score which included Landing Error Scoring System (LESS) scores, asymmetries in single-leg squat endurance ($>15\%$ asymmetry), and signs of performance decrements due to fatigue. Injuries were recorded as a binary variable (injured vs not injured) and were confirmed by medical-marked clinicians, taking into verification known diagnostic criteria for ACL injury.

Statistical Analysis

Descriptive statistics were calculated for all variables of interest for all positions. Logistic regression was employed to determine significant predictors of ACL injury, presenting odds ratios (ORs) and 95% confidence intervals. One-way ANOVA was employed to compare training load, fatigue, on field performance measures and ACL risk indexes between positional groups with Tukey's HSD post-hoc comparisons for the variables that border on significance. Pearson correlation coefficients were computed to establish relationships between load, fatigue, and risk related variables. The entire statistical analyses were carried out using SPSS v25 (Rashid, 2016) with a significance level set at $\alpha = 0.05$ and a Bonferroni correction used to accommodate possible Type I error resulting from multiple comparisons.

Results

A total of 93 male collegiate handball players completed the full monitoring protocol over two competitive seasons (AY 2022–2024), yielding a complete dataset for training load, fatigue, performance, and injury outcomes. All participants met the inclusion criteria, with a mean age of 20.8 ± 1.6

Table 1. Descriptive Statistics by Player Position

Variable	Centre Back	Left Back	Right Back
Age (years)	20.96 ± 1.95	21.11 ± 2.12	21.26 ± 1.53
Height (cm)	180.86 ± 13.18	178.87 ± 11.00	182.93 ± 12.56
Weight (kg)	80.64 ± 13.55	77.08 ± 11.59	81.96 ± 9.33
Training Intensity (CR-10)	6.32 ± 2.02	5.32 ± 2.27	4.93 ± 2.40
Training Hours/Week	11.18 ± 4.60	10.79 ± 4.74	12.07 ± 4.17
Recovery Days/Week	2.21 ± 0.79	2.00 ± 0.84	1.85 ± 0.72
Match Count/Week	1.96 ± 1.10	2.50 ± 1.11	2.37 ± 1.21
Fatigue Score (0–10)	5.29 ± 2.61	4.74 ± 2.60	5.93 ± 2.46

Note: Values are reported as mean ± standard deviation (SD). No inferential statistics were applied in this table; comparisons are descriptive only. Significance level: Statistical significance for inferential comparisons is reported in subsequent analyses at $p < 0.05$.

years. Across the study period, a total of 18 confirmed ACL injuries were recorded. The following subsections present the findings in sequential order: descriptive statistics, injury incidence and risk scores, predictive modelling of injury risk, and positional differences in key variables.

The descriptive analysis reveals consistent participation levels across positions, with comparable distributions in training exposure and fatigue measures. Mean training hours per week were slightly higher among Left Back (10.31 ± 2.78), followed by Right Back and Centre Back, suggesting marginal positional differences in physical demands. Fatigue scores showed less variability, with Right Back reporting slightly elevated perceived fatigue (mean = 5.85 ± 1.01), potentially reflecting the intensity and frequency of high-speed demands typical of this position. The consistency in CMJ and performance scores across groups supports general homogeneity in conditioning levels, although subtle position-specific variations may warrant further exploration in relation to injury patterns.

Table 2. Injury Incidence and ACL Risk Scores by Position and Load Category

Position	Injuries (n)	Total (n)	Injury Rate (%)	ACL Risk Score (Mean ± SD)
By Player Position				
Centre Back	2	28	7.14 %	50.86 ± 17.93
Left Back	2	38	5.26 %	43.45 ± 17.74
Right Back	2	27	7.41 %	52.22 ± 20.09
By Training Load Category (Weekly Hours)				
Low	1	31	3.23 %	45.39 ± 16.10
Medium	2	33	6.06 %	45.94 ± 18.66
High	3	29	10.34 %	53.86 ± 20.74

Note: Injury incidence is reported as percentage of injured players per category. ACL risk scores represent composite values derived from limb asymmetry, fatigue markers, and LESS criteria. Significance level: Group differences assessed in later analyses; threshold for significance was set at $p < 0.05$.

ACL injury incidence was highest among Right Back (7.41%) and Centre Back (7.14%), while Left Back showed a slightly lower incidence (5.26%). This trend may reflect biomechanical and tactical differences, as backcourt players

frequently engage in high-impact movements such as cutting, jumping, and pivoting under defensive pressure. Notably, the highest ACL risk score was also observed among Right Back (mean = 52.22 ± 20.09), further supporting the role of positional demands in predisposing athletes to non-contact knee injuries.

When stratified by training load category, players in the high-load group demonstrated the highest ACL injury rate (10.34%) and the greatest mean ACL risk score (53.86 ± 20.74), as summarized in Table 2. This pattern suggests a potential dose–response relationship, where increasing training demands may elevate the physiological strain associated with injury risk.

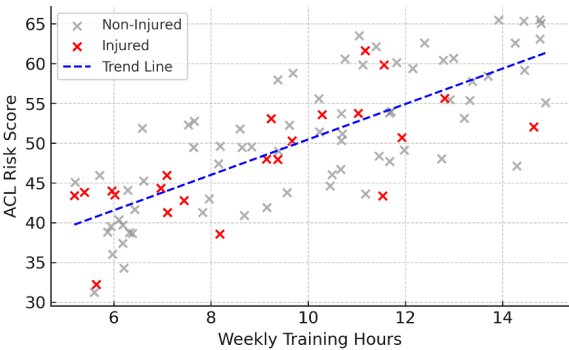


Fig. 1. Training Load Vs. ACL Risk

To further explore this relationship, Figure 1 presents a scatterplot depicting individual weekly training hours in relation to ACL risk scores. The scatterplot reveals a clear positive trend, indicating that athletes with higher training loads tend to exhibit elevated ACL risk scores. Notably, players who sustained injuries (highlighted in red) are more concentrated in the upper range of both training hours and risk scores, suggesting that cumulative external load may play a critical role in injury susceptibility.

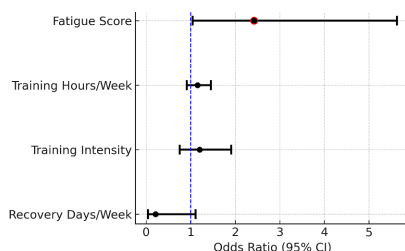
Multivariate logistic regression identified fatigue score as the only statistically significant predictor of ACL injury ($\beta = 0.884$, $p = 0.041$). The odds ratio of 2.42 suggests that for each one-unit increase in fatigue score, the likelihood of sustaining an ACL injury more than doubles. This reinforces the importance of subjective fatigue monitoring in injury prevention models and supports fatigue as a critical modifiable risk factor in load management protocols.

Table 3. Logistic Regression Predicting ACL Injury Occurrence

Variable	β Coefficient	Std. Error	p	Odds Ratio (OR)
Intercept (const)	-9.000	4.328	0.038	0.00
Training Intensity	0.182	0.234	0.438	1.20
Training Hours/Week	0.141	0.120	0.238	1.15
Fatigue Score	0.884	0.433	0.041	2.42
Recovery Days/Week	-1.539	0.831	0.064	0.21

Note: Odds ratios (OR) with 95% confidence intervals (CI) are reported for each predictor variable. Model fit assessed using Nagelkerke R^2 and Hosmer–Lemeshow goodness-of-fit test. Significance level: $p < 0.05$ considered statistically significant

Although not statistically significant, recovery days per week demonstrated a protective trend ($OR = 0.21, p = 0.064$), indicating that structured recovery may mitigate injury risk. Neither training intensity nor weekly training hours were significant predictors, although both showed small positive associations with injury likelihood. These findings suggest that injury risk is more closely tied to recovery adequacy and accumulated fatigue than to training volume alone.

**Fig. 2.** logistic regression predictors of ACL injury

To visually summarize the predictive strength of each variable, a forest plot was constructed (Figure 2), displaying odds ratios and corresponding 95% confidence intervals. The figure highlights fatigue score as the most prominent risk factor, while illustrating the nonsignificant but directionally relevant roles of other load-related variables.

Table 4. ANOVA Results for Positional Differences

Variable	F	p
Training Hours/Week	0.642	0.529
Training Intensity	2.907	0.060
Fatigue Score	1.704	0.188
Performance Score	1.778	0.175
ACL Risk Score	2.180	0.119

Note: One-way ANOVA used to test differences among player positions. Variables with $p < 0.05$ were subjected to post hoc analysis using Tukey's HSD test. Significance level: $p < 0.05$. Bonferroni correction applied where multiple comparisons were performed.

Table 5. Post Hoc Analysis: Training Intensity by Position (Tukey HSD)

Comparison	Mean Difference	p	95% CI (Lower – Upper)	Significant
Centre Back vs Left Back	-1.01	0.174	[-2.33, 0.32]	No
Centre Back vs Right Back	-1.40	0.059	[-2.83, 0.04]	No (borderline)
Left Back vs Right Back	-0.39	0.768	[-1.73, 0.95]	No

Note: Pairwise comparisons conducted using Tukey's Honestly Significant Difference (HSD) test. Results indicate which positional differences in training intensity reached statistical significance. Significance level: Post hoc results were interpreted at $p < 0.05$ following a significant ANOVA main effect.

ANOVA revealed no statistically significant differences among positions across the five variables examined. However, training intensity approached significance ($F = 2.91, p = 0.060$), suggesting a trend toward positional variation in internal load. This preliminary signal was further explored through post hoc testing (Table 4), which identified a near-significant difference between Centre Back and Right Back (mean difference = -1.40, $p = 0.059$). Such a trend may reflect distinct tactical roles and physiological profiles associated with each position, wherein Centre Back are typically involved in both playmaking and defensive transitions.

Fatigue score, performance metrics, and ACL risk scores did not differ significantly by position, which may reflect uniformity in training programs or small sample variation. Nevertheless, the positional trends observed warrant continued investigation using larger samples and multilevel modelling approaches to capture the complexity of positional demands in collegiate handball.

Discussion

The study followed a two-season prospective cohort and revealed significant associations between perceived fatigue and ACL injury incidence in collegiate male handball players. Among all factors analyzed, fatigue score was the only statistically significant variable for ACL injury ($OR = 2.42, p = 0.041$), meaning that athletes who considered themselves more fatigued were twice-and-a-half times more likely to sustain an ACL injury. This is in line with several proposals stating that neuromuscular fatigue lessens the ability of the muscle system to assure dynamic stability and sensorimotor control, thereby heightening injury risk during high-load activities, such as deceleration, cutting, and landing (Méjane et al., 2019) (Larson et al., 2018).

On the other hand, cases in high training load situations registered injury rates higher than 10.34% and ACL risk scores (Bowen et al., 2017), hence strengthening the relevance of insufficient recovery from an increased external load. Injuries showed no statistically significant difference in relation to training intensity and total hours within the regression models, yet the directional association with injury susceptibility has been reported elsewhere (Ertel et al., 2020) (Batterson et al., 2020), thereby confirming load and recovery-based interaction as the principal factors determining injury risk (Yung et al., 2023). The tendency for greater risks in Right Back and Centre Back may relate to position-specific movement demands involving lateral movements and high-frequency contacts stressing the knee joint complex.

In agreement with the literature complaint fatigue and poor load management as primary risk factors for lower extremity injuries within team sports (Payne et al., 2023), these findings are observed. Past studies have also stated that fa-

tigue disturbs the joint stabilization and alters the lower limb kinematics upon landing and pivoting in elite and youth-handball populations (Payne et al., 2023; Rostami et al., 2018). Relevant associations have also been evinced in fellow pivot-dominant sports like basketball and soccer wherein neuromuscular fatigue has been suggested to increase lesser knee flexion angles and greater valgus moments, both implicated in ACL injury mechanisms (Bourne et al., 2019; Parker et al., 2022). These results further emphasize the development of training and recovery programs to prevent ACL injuries, especially in sports of high intensity, such as handball.

Our results add to the evidence produced in Favor of the short-ACWR model, in those abrupt increments in training load, especially when paired with insufficient recovery time, tend to increase injury risk (Andrade et al., 2020). However, our study extends the body of literature on this matter by considering subjective fatigue measures alongside field-based ACL risk screening (LESS scores, limb asymmetry), thereby allowing for a more integrated evaluation of injury susceptibility than studies that rely solely on biomechanical or performance variables.

Hence, monitoring fatigue and individualized load management are essential in collegiate handball settings. Subjective tools, such as a daily wellness questionnaire, could be a cheap, sensitive indicator of the accumulated neuromuscular strain. Suppose after crossing a certain critical fatigue threshold, either modified training protocols or extra recovery days or even neuromuscular reconditioning are given to athletes. In that case, the incidence of injuries could drastically be lowered (Sampson et al., 2019). Next, we suggest position-specific interventions. Because of the heightened risk among right-Back and Centre Back, neuromuscular training (perturbation training, single-leg stability exercises) that specifically addresses these players should be added into their weekly training schedule (Yamchi et al., 2022).

At the same time, internal loads should be monitored (session-RPE) along with the external (mean training hours, sprint volume) to avoid overuse and decreases in abrupt increments of ACWR (Andrade et al., 2020). When possible, to alleviate accumulated joint stress, performance staff may wish to consider rotating higher risk players or staggering their heavy sessions.

A very strong aspect of this study by Zemková et al. (2020) is its prospective nature over two competitive seasons, thus making greater temporal inference about causality possible than with retrospective analyses. Furthermore, in the load monitoring procedure, a wide spectrum of parameters was measured, ranging from subjective ones (fatigue, wellness scores) to objective ones (training duration, performance outcomes), thus increasing its ecological validity and real-world applicability.

A few limitations, however, need to be acknowledged. First, the sample was limited to male collegiate handball athletes, which limits generalization to female athletes or other levels of play. Previous research has shown sex-specific biomechanical and hormonal differences in ACL injury mechanisms, which were not considered by this study. Second, although field-based fatigue markers such as CMJ decline are practical, they may not be as sensitive as laboratory-grade measures (e.g., electromyography, isokinetics) at detecting subclinical neuromuscular deficits. Third, even if using self-reported training data and coach logs may introduce recall or reporting bias, the use of standardized monitoring procedures probably limits this possibility.

Conclusions

The present study is the first to provide prospective evidence concerning the association between training load, fatigue, and the risk of ACL injury in collegiate male handball players. Fatigue was found to be the strongest predictor for ACL injury, with injury risk more than doubling for high subjective fatigue scores. Those players experiencing high records of training load without sufficient recovery were again found to have high risk profiles for ACLs, whereas such players were concurrently prone to experiencing far greater injury incidence levels, stressing the role of proper load management on injury prevention.

This, consequently, demands the coaching staff and sports scientists to monitor fatigue systematically by using simple tools such as well-being questionnaires and jump performance as part of their routine training oversight. Doing so, while monitoring the internal and external loads regularly, especially for positional groups deemed at risk such as the Right and Centre Back, will allow for the identification of at-risk athletes before injuries occur.

These findings provide valuable insights for educators, coaches, and sports scientists working with collegiate athletes. By incorporating simple monitoring tools into physical education programs, institutions can better manage athlete workload, reduce injury risk, and improve performance sustainability.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Тренувальне навантаження, втома та ризик травмування передньої хрестоподібної зв'язки у студентів-гандболістів чоловічої статі: Двосезонне проспективне когортне дослідження

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Історія питання. Травмування передньої хрестоподібної зв'язки (ПХЗ) становить суттєву проблему в змагальному гандболі, що часто призводить до тривалої відсутності гравця та зниження спортивної результативності. З огляду на високі фізичні вимоги до цього виду спорту, особливо на студентському рівні, моніторинг тренувального навантаження та втоми є надзвичайно важливим для зменшення ризику травмування.

Мета дослідження. Мета цього дослідження полягала у вивченні взаємозв'язку між тренувальним навантаженням, маркерами втоми та ризиком травмування передньої хрестоподібної зв'язки у студентів-гандболістів чоловічої статі впродовж двох змагальних сезонів.

Матеріали та методи. Проведено проспективне когортне дослідження за участю 93 спортсменів-чоловіків (середній вік: 20.8 ± 1.6 року) з 13 студентських гандбольних команд протягом двох сезонів (2022-2024 навчальні роки). Тренувальне навантаження відстежувалося за допомогою щотижневих годин, тренувальних сесій, в яких інтенсивність вправ регулювалася на основі індивідуального сприйняття навантаження та рівня ризику отримання травмування під час матчів. Оцінка рівня втоми проводилася через щоденні показники самопочуття та зниження висоти стрибка з контррухом (СКР). Ризик травмування ПХЗ розраховувався на основі комбінованого балу, що включав показники LESS (система оцінювання помилок під час приземлення), асиметрію кінцівок та зниження результативності, пов'язане з втомою. З метою визначення предикторів травми ПХЗ використовувалася логістична регресія, а позиційні відмінності досліджувалися за методом дисперсійного аналізу.

Результати. Показник втоми був єдиним статистично значущим предиктором травми передньої хрестоподібної зв'язки ($p = 0.041$). Гравці, які повідомляли про вищий рівень втоми і належали до групи з високим тренувальним навантаженням, мали найбільший ризик травмування передньої хрестоподібної зв'язки. Праві та центральні захисники стикалися з більшими тренувальними навантаженнями та накопиченням втоми порівняно з лівими захисниками.

Висновки. Результати дослідження свідчать, що постійна втома, як чинник, що має більший вплив, ніж обсяг тренувань, є значущим предиктором ризику травмування передньої хрестоподібної зв'язки у студентів-гандболістів. Інтеграція регулярного моніторингу втоми та індивідуального контролю навантажень до тренувальних програм може сприяти зниженню рівня травматизму та покращенню спортивного довголіття.

Ключові слова: травма передньої хрестоподібної зв'язки, тренувальне навантаження, моніторинг втоми, профілактика травмування, нервово-м'язовий скринінг, спортивна результативність у гандболі.

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Using Different Types of Exercise Can Have Varied Effects on Fat Mass and Muscle Mass in Obese Females

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Abstract

Objectives. This study aimed to compare the effects of aerobic and resistance training on improving body composition in obese women.

Materials and methods. This study used a true-experimental pretest-posttest control group design. A total of 33 obese women aged 23.21 ± 1.36 years, with a body mass index of 29.11 ± 3.35 kg/m², and a body fat percentage of 33.99 ± 2.55 %, were selected from female students in Malang City to be given an aerobic training (Aerobic) and resistance training (Resistance) intervention program for 8 weeks. Baseline (pre) and week 8 (post) body composition assessments were performed using the Body composition analyzer LN-GS6.5C. Statistical analysis was applied using the Two-Way Repeated Measures ANOVA, followed by LSD post-hoc test, with a significance level of 5 %.

Results. The results showed that delta (Δ) body weight, body mass index, body fat, and body fat percentage were found to have experienced a significant reduction, while skeletal muscle mass increased substantially after undergoing aerobic training and resistance training intervention programs compared to baseline (pre) ($p < 0.05$). Aerobic training was found to be more effective in reducing body fat, while resistance training was effective in increasing skeletal muscle mass ($p < 0.05$).

Conclusions. These findings indicate that both training models have different effects on reducing body fat and increasing skeletal muscle mass in obese women.

Keywords: aerobic training, body composition, healthy lifestyle, obesity, resistance training.

Introduction

Beyond its effects on metabolism, obesity significantly impacts muscle function (Valenzuela et al., 2020). In some individuals, a condition known as sarcopenic obesity, characterized by excessive fat mass combined with low muscle mass, is observed (Donini et al., 2022). This condition raises serious concerns as it exacerbates the risks of physical disability, reduced mobility, and diminished quality of life (Petroni et al., 2019). Numerous studies have explored the relationship between obesity and muscle quality (Tomlinson

et al., 2016; Tallis et al., 2018; da Costa Teixeira et al., 2024). Consistent findings indicate that in obese individuals, muscle quality tends to decline, negatively affecting the contractile capacity of skeletal muscles (Lafortuna et al., 2014; Choi et al., 2016). For instance, Lafortuna et al. (2014) reported that high adiposity negatively correlates with muscle lipid levels, ultimately impairing contractile ability in both men and women. Similarly, Choi et al. (2016) demonstrated that myofibers in obese individuals exhibit decreased functionality, leading to reduced muscle strength. These findings are further supported by studies showing that muscle strength in obese populations is significantly lower than in individuals with normal body weight (Bollinger, 2017). The decline in muscle quality and strength not only worsens metabolic disorders but also reduces functional capacity in daily activities.

Physical exercise has long been recommended as a primary approach to addressing obesity (Johnson et al., 2021; Strain et al., 2024). Aerobic exercise, which involves rhythmic activities using large muscle groups continuously, is often regarded as an effective method for reducing body fat mass and improving metabolic health (Liu et al., 2022). Several studies support the effectiveness of aerobic exercise in weight reduction, primarily through significant calorie burning and the utilization of fat reserves as the main energy source (Oppert et al., 2024; Güzel et al., 2024). A recent meta-analysis revealed that aerobic exercise results in greater fat mass reduction compared to other types of exercise, making it a popular choice among obese individuals (Ismail et al., 2011). However, a significant drawback of this exercise modality is often overlooked. Some studies indicate that aerobic exercise not only reduces fat mass but may also decrease muscle mass if not accompanied by adequate nutrition or complementary exercises (Villareal et al., 2017). This loss of muscle mass is a particular concern for obese populations, given the crucial role of muscles in maintaining basal metabolism and supporting physical function (Mengeste et al., 2021).

As an alternative, resistance training has gained increasing attention in the context of obesity management (Liu et al., 2022). This type of exercise involves the use of weights or resistance to stimulate muscle contraction, aiming to increase muscle mass and physical strength (Semlitsch et al., 2019). Resistance training is considered an anabolic approach as it stimulates muscle protein synthesis and prevents muscle mass loss during weight reduction (Carneiro et al., 2024). Previous research has demonstrated that resistance training positively impacts muscle mass, strength, and physical function (Paluch et al., 2023). Additionally, resistance training has been shown to improve insulin sensitivity, which is crucial in managing obesity and related metabolic disorders (Boyer et al., 2023). Therefore, this type of exercise is not only effective in enhancing muscle mass but also provides broader health benefits for obese individuals.

While resistance training provides various health benefits, the broader question of how different exercise types affect specific components of body composition in obese females remains underexplored. Several meta-analyses and randomized controlled trials have examined the effects of aerobic, resistance, and combined exercise training on fat mass in overweight and obese populations (Ho et al., 2012; Schroeder et al., 2019; Amare et al., 2024; Lafontant et al., 2025; Liu et al., 2024; Lee et al., 2024). Although these studies consistently report that exercise, particularly combined training, improves fat loss and metabolic outcomes, they typically focus on fat mass alone and often involve mixed-gender or heterogeneous samples. Furthermore, only a limited number of studies have directly compared the isolated effects of aerobic versus resistance training on both fat mass and muscle mass in obese women, using standardized protocols and validated body composition measures. Therefore, there remains a critical gap in the literature concerning how different exercise modalities uniquely affect fat and muscle mass in this specific population. Addressing this gap is essential for developing evidence-based, gender-specific exercise recommendations for obesity management.

This study aims to evaluate and compare the effects of aerobic and resistance training on body composition

changes in obese females. Specifically, it focuses on how aerobic training can help reduce body fat mass, while resistance training is hypothesized to increase muscle mass significantly. Based on the existing literature, we hypothesize that fat mass reduction will be significant in the aerobic training group. In contrast, muscle mass increase will be more pronounced in the resistance training group. The findings of this study are expected to provide evidence-based guidelines for obesity management in women, emphasizing the importance of selecting exercise types that align with desired body composition goals.

Materials and Methods

Study Design

This study was a true-experimental research with a pretest-posttest control group design. The study involved 33 female university students from the Malang region as participants. Obesity was defined based on the international diagnostic criteria for clinical obesity by The Lancet Diabetes & Endocrinology, using a BMI cut-off of ≥ 27 kg/m² and body fat percentage $\geq 30\%$ for Asian populations (Rubino et al., 2025). Inclusion criteria included: age 20–25 years, BMI ≥ 27 kg/m², BFP $\geq 30\%$, absence of chronic diseases, non-smoker, no alcohol use in the past five years, and willingness to participate for 8 weeks. Participants were randomly divided into three groups: Control ($n = 11$; control group), Aerobic ($n = 11$; aerobic training group), and Resistance ($n = 11$; resistance training group). Before participation, all participants were provided with detailed information about the study's objectives, benefits, and risks. Those who voluntarily agreed to participate were required to complete and sign an informed consent form. This study adhered to the principles outlined in the World Medical Association's Declaration of Helsinki (1975) and received ethical approval from the Health Research Ethics Committee of the Faculty of Medicine, Universitas Airlangga, on June 19, 2024 (Approval No: 32/EC/KEPK/FKUA/2024).

Training Program Protocol

The training program was conducted at Atlas Sports Club Malang (Indonesia) every morning from 07:00 to 09:00 AM, three times per week over eight weeks. Each session was supervised by certified fitness instructors and research staff. Before each session, participants completed a 5-minute warm-up (stretching and light aerobic movements), and ended with a 5-minute cooldown on a treadmill at a low pace. Aerobic training was performed at 60–70% of estimated maximal heart rate (HR_{max}), calculated using the formula $220 - \text{age}$. Each session lasted 40–60 minutes and was conducted continuously on a treadmill (Life Fitness™). Resistance training was performed using Cybex machines (pull-down, chest press, shoulder press, leg press, leg curl, leg extension). The intensity was set at 60–70% of 1-repetition maximum (1-RM). 1-RM was estimated using submaximal testing and calculated with the Brzycki formula (Brzycki, 1993). Each session consisted of 4–6 sets of 12–15 repetitions, performed in intervals. The control group did not receive any intervention. All sessions were carried out in a controlled room with an ambient temperature of $25 \pm$

Table 1. Detailed training program protocol

Training Model	Frequency	Intensity	Type	Time	Tools
Aerobic training	3x/week during 8 weeks	60-70% HRmax	Continuous	40-60 minutes/session	Life fitness treadmill 95T
Resistance training	3x/week during 8 weeks	60-70% 1-RM	Interval	4-6 sets with 12-15 reps/session	Cybox: Pull down Shoulder press Chest press Leg press Leg extension Leg curls
Control group	Did not receive any intervention for 8 weeks				

1°C and a humidity level of 50–60%. Details of the training program are presented in Table 1.

Data Collection

Data collection involved the assessment of body weight (BW), body mass index (BMI), body fat (BF), body fat percentage (BFP), and skeletal muscle mass (SMM) at baseline (pre) and the 8th week (post) using a Body Composition Analyzer LN-GS6.5C.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows version 21.0. Paired sample t-tests were applied to evaluate within-group differences between pre-intervention and post-intervention for data with a normal distribution. Additionally, Two-Way Repeated Measures ANOVA and the Least Significant Difference (LSD) post-hoc test were used to assess between-group differences for data with a normal distribution and homogeneous variances. All data were presented as mean $\pm$ standard deviation (SDs).

Results

The results of the baseline assessment of the characteristics of the participants are presented in detail in Table 2. No significant differences were found in all parameters of the participants' characteristics (all $p > 0.05$). Meanwhile, the results of the analysis of body weight (BW), body mass index (BMI), body fat (BF), body fat percentage (BFP), and skeletal muscle mass (SMM) between baseline (pre) and week 8 (post) are presented in Figures 1-5 and Table 3.

As shown in Table 3, statistically significant changes were observed in body composition parameters following the 8-week intervention. In the aerobic group, BMI de-

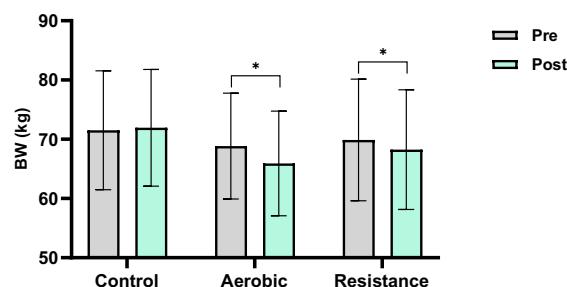


Fig. 1. Body weight (BW) assessment at baseline (pre) and week 8 (post). Data are presented as mean $\pm$ SDs. p-value was obtained by using paired sample t-test. *Significant at pre ($p < 0.05$)

Table 2. Characteristics of the participants of the study

Characteristics	Control (n = 11)	Aerobic (n = 11)	Resistance (n = 11)	P
Age, yrs	23.09 $\pm$ 1.44	23.18 $\pm$ 1.41	23.36 $\pm$ 1.36	0.898
SBP, mmHg	115.54 $\pm$ 3.15	115.81 $\pm$ 3.41	116.04 $\pm$ 3.09	0.936
DBP, mmHg	72.59 $\pm$ 5.91	73.54 $\pm$ 4.66	72.90 $\pm$ 4.72	0.906
RHR, bpm	73.86 $\pm$ 4.21	73.45 $\pm$ 6.84	75.63 $\pm$ 5.78	0.640
SpO ₂ , %	97.72 $\pm$ 1.11	97.90 $\pm$ 1.04	97.91 $\pm$ 1.13	0.904
BT, °C	36.29 $\pm$ 0.44	36.45 $\pm$ 0.26	36.33 $\pm$ 0.29	0.524
FBG, mg/dL	90.63 $\pm$ 5.85	89.72 $\pm$ 7.01	91.00 $\pm$ 4.81	0.876
Hb, g/dL	14.75 $\pm$ 1.14	15.07 $\pm$ 1.17	14.73 $\pm$ 1.25	0.759
Height, m	1.56 $\pm$ 0.05	1.54 $\pm$ 0.04	1.55 $\pm$ 0.04	0.385
Pre-BW, kg	71.51 $\pm$ 10.02	68.85 $\pm$ 8.93	69.89 $\pm$ 10.26	0.813
Pre-BMI, kg/m ²	29.03 $\pm$ 4.06	29.05 $\pm$ 2.70	29.25 $\pm$ 3.47	0.986
Pre-BF, kg	24.71 $\pm$ 5.01	23.93 $\pm$ 7.64	23.10 $\pm$ 4.57	0.814
Pre-BFP, %	34.17 $\pm$ 2.46	34.29 $\pm$ 3.25	33.52 $\pm$ 1.93	0.763
Pre-SMM, kg	23.85 $\pm$ 3.81	24.67 $\pm$ 3.07	24.71 $\pm$ 3.14	0.798

Description: SBP: Systolic blood pressure; DBP: Diastolic blood pressure; RHR: Resting heart rate; SpO₂: Oxygen saturation; BT: Body temperature; FBG: Fasting blood glucose; Hb: Hemoglobin. Data are presented as mean $\pm$ standard deviation (SDs). p-value was obtained by using Two-Way Repeated Measures ANOVA.

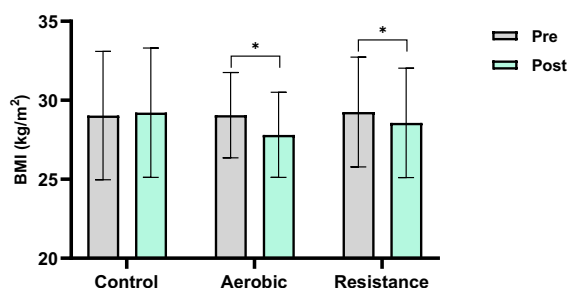


Fig. 2. Body mass index (BMI) assessment at baseline (pre) and week 8 (post). Data are presented as mean $\pm$ SDs. p-value was obtained by using paired sample t-test. *Significant at pre ($p < 0.05$)

creased from 29.21 ± 4.09 to 27.81 ± 2.69 , while in the resistance group it decreased from 28.57 ± 3.45 to 28.57 ± 3.45 , with no significant change in the control group. Although the BMI reduction observed in the aerobic group was sta-

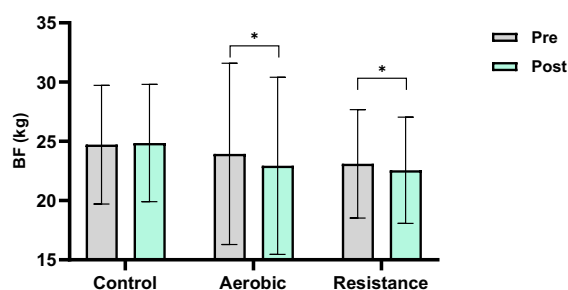


Fig. 3. Body fat (BF) assessment at baseline (pre) and week 8 (post). Data are presented as mean $\pm$ SDs. p-value was obtained by using paired sample t-test. *Significant at pre ($p < 0.05$)

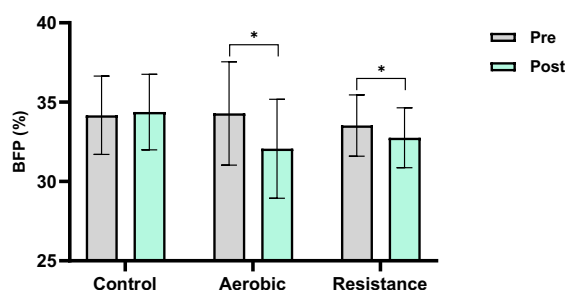


Fig. 4. Body fat percentage (BFP) assessment at baseline (pre) and week 8 (post). Data are presented as mean $\pm$ SDs. p-value was obtained by using paired sample t-test. *Significant at pre ($p < 0.05$)

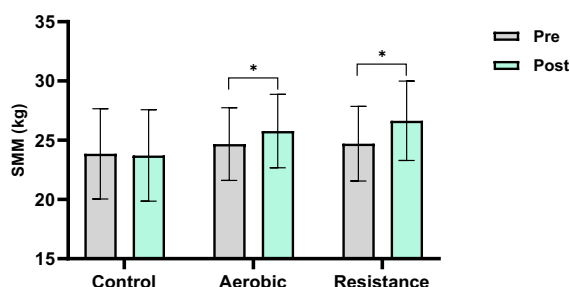


Fig. 5. Skeletal muscle mass (SMM) assessment at baseline (pre) and week 8 (post). Data are presented as mean $\pm$ SDs. p-value was obtained by using paired sample t-test. *Significant at pre ($p < 0.05$)

tistically significant ($p < 0.001$), participants remained in the overweight category ($\text{BMI} > 25$). From a clinical standpoint, this level of change may appear modest. However, growing evidence suggests that improvements in body composition—such as reduced body fat percentage and increased skeletal muscle mass—are more indicative of health risk reduction than BMI alone. Therefore, the observed reductions in body fat percentage ($\Delta\text{-BFP}$: -2.22%) and increases in muscle mass ($\Delta\text{-SMM}$: $+1.11$ kg in the aerobic group, $+1.93$ kg in the resistance group) highlight the clinical value of these interventions despite minimal categorical shifts in BMI classification.

Discussion

This study aimed to evaluate the effects of aerobic and resistance training on changes in body fat and muscle mass in

Table 3. Body composition assessment at baseline (pre) and week 8 (post) between group

Parameters	Control (n = 11)	Aerobic (n = 11)	Resistance (n = 11)	p
Post-BW, kg	71.93 $\pm$ 9.85	65.91 $\pm$ 8.83	68.25 $\pm$ 10.11	0.347
Post-BMI, kg/m ²	29.21 $\pm$ 4.09	27.81 $\pm$ 2.69	28.57 $\pm$ 3.46	0.639
Post-BF, kg	24.85 $\pm$ 4.95	22.94 $\pm$ 7.47	22.55 $\pm$ 4.48	0.613
Post-BFP, %	34.37 $\pm$ 2.38	32.06 $\pm$ 3.11	32.75 $\pm$ 1.88	0.102
Post-SMM, kg	23.71 $\pm$ 3.86	25.77 $\pm$ 3.11	26.63 $\pm$ 3.34	0.142
$\Delta\text{-BW}$, kg	0.41 $\pm$ 0.82	-2.93 $\pm$ 0.67 ^{ac}	-1.63 $\pm$ 0.37 ^a	0.000
$\Delta\text{-BMI}$, kg/m ²	0.18 $\pm$ 0.33	-1.24 $\pm$ 0.29 ^{ac}	-0.68 $\pm$ 0.12 ^a	0.000
$\Delta\text{-BF}$, kg	0.13 $\pm$ 0.27	-0.99 $\pm$ 0.26 ^{ac}	-0.54 $\pm$ 0.14 ^a	0.000
$\Delta\text{-BFP}$, %	0.21 $\pm$ 0.39	-2.22 $\pm$ 0.86 ^{ac}	-0.77 $\pm$ 0.16 ^a	0.000
$\Delta\text{-SMM}$, kg	-0.13 $\pm$ 0.28	1.11 $\pm$ 0.26 ^a	1.93 $\pm$ 0.61 ^{ab}	0.000

Description: Data are presented as mean $\pm$ standard deviation (SDs). p-value was obtained by using Two-Way Repeated Measures ANOVA and following by LSD post-hoc test. aIndicates a significant difference with the control group ($p < 0.001$). bIndicates a significant difference with the aerobic group ($p < 0.001$). cIndicates a significant difference with the resistance group ($p < 0.001$).

obese females. The results demonstrated that aerobic training was effective in significantly reducing body fat, while resistance training resulted in greater muscle mass gain. These findings support the understanding of evidence-based exercise effectiveness for improving body composition in obese females. Although the changes in fat and muscle mass observed in this study were statistically significant, their clinical relevance is equally important. Improvements in body composition, even when not accompanied by large reductions in total body weight, have been associated with better metabolic health, increased functional capacity, and reduced risk of chronic conditions in individuals with obesity. For obese females in particular, decreasing fat mass while increasing muscle mass contributes to improved mobility, hormonal balance, and long-term weight maintenance. These outcomes highlight that exercise interventions yielding statistically significant changes in fat or muscle mass can have meaningful implications for clinical practice, especially in designing targeted, sustainable obesity management programs.

Our results are consistent with previous studies that found aerobic training to be superior to resistance training in reducing body fat (Willis et al., 2012). Additionally, a meta-analysis comparing the effects of aerobic and resistance training on body fat concluded that greater body fat reduction occurred in the aerobic training group compared to the resistance training group (Ismail et al., 2011). These findings are consistent with prior studies demonstrating the effectiveness of aerobic training in reducing body fat. For example, Keating et al. (2017) reported that aerobic exercise could reduce body fat by up to 1.26%, while Weweg et al. (2022) observed reductions of 1.4% in body fat percentage. Schwingshackl et al. (2013) also showed an average fat mass reduction of approximately 1 kg following aerobic programs. Such evidence reinforces the role of aerobic training as a reliable modality for fat mass reduction in obese individuals.

In addition to reducing body fat, aerobic training has been consistently associated with broader health benefits. Previous studies have reported that aerobic exercise contributes to improved cardiovascular health, lower metabolic risk, and better functional capacity among individuals with obesity (Lopez et al., 2022). Moreover, aerobic programs have been shown to positively influence bone mineral density and support the preservation of lean body mass (Stonehouse et al., 2016). These findings reinforce the role of aerobic training as a foundational component of comprehensive obesity management.

Our findings also highlight that resistance training was more effective than aerobic training in increasing muscle mass. This aligns with several studies, including Schoenfeld et al. (2016), which demonstrated significant hypertrophy following an 8-week high-intensity program. Increases in muscle strength have also been reported among obese women engaged in resistance training, as evidenced by 1-RM testing results (Zemková et al., 2017; Sarsan et al., 2006). Systematic reviews have emphasized that muscle hypertrophy is especially pronounced when exercises are performed to voluntary fatigue, particularly in untrained individuals (Toth et al., 2012; Lopez et al., 2020). These outcomes underscore the importance of resistance training in enhancing muscle mass and physical performance as part of obesity intervention programs.

Although this study examined aerobic and resistance training separately, evidence suggests that combining the two may produce synergistic effects. For instance, Willis et al. (2012) demonstrated that combined training not only accelerates fat loss but also promotes muscle gain, resulting in more holistic improvements in body composition. This integrated approach may be particularly beneficial for obese women, who often require strategies targeting both fat reduction and muscle preservation. Future studies are needed to determine the optimal structure, duration, and intensity of combined training interventions for this population.

The physiological mechanisms underlying the effects of aerobic and resistance training on body composition are distinct and complementary. Aerobic training enhances mitochondrial density within skeletal muscle, promoting the efficient breakdown of triglycerides into free fatty acids to meet increased energy demands (Brooks, 2020; Hargreaves & Spriet, 2020). This type of exercise also activates AMP-activated protein kinase (AMPK) and intracellular calcium pathways, which upregulate GLUT-4 expression and facilitate greater glucose and fatty acid uptake during muscle contraction (Richter & Hargreaves, 2013). Additionally, aerobic training increases fatty acid oxidation capacity, reduces reliance on glycogen, and lowers lactate production, thereby improving metabolic efficiency during prolonged activity (El-Zayat et al., 2019; Brooks, 2020). In contrast, resistance training induces muscle hypertrophy and enhances neuromuscular adaptations through the stimulation of muscle protein synthesis. This process is supported by the activation of GLUT-4 via the transcriptional coactivator PGC-1 α , which also plays a role in mitochondrial biogenesis, particularly in type I muscle fibers (Kido et al., 2016). Furthermore, the increase in lean muscle mass contributes to a higher basal metabolic rate, which is critical for long-term energy balance and obesity management (Mitchell et al., 2012). These mechanisms explain the differential effects observed in this study and reinforce the value of exercise specificity in targeting fat loss or muscle gain.

This study has several limitations. First, the relatively short intervention duration (8 weeks) may not be sufficient to evaluate the long-term effects of both exercise types on body composition. Previous studies have shown that combining exercises requires more than 12 weeks to yield significant results (Willis et al., 2012). Second, the sample size, which was limited to obese females, restricts the generalization of findings to other populations, such as obese males or individuals with other comorbidities. Third, this study did not measure additional physiological variables, such as hormone levels or other metabolic parameters, which could provide deeper insights into the body's response to exercise.

Future research directions should include long-term evaluations of combined aerobic and resistance training in obese females, particularly to assess sustained changes in body composition and metabolic health. Given that the average age of participants in this study was relatively young (23 years), these findings can be seen as a form of early preventive intervention. Since obesity-related complications such as type 2 diabetes, hypertension, and cardiovascular disease are more prevalent in older adults, it is important to ensure that early improvements observed in younger populations can be maintained or enhanced in older age groups. Investigating these interventions across different life stages may help inform comprehensive, age-appropriate strategies for obesity management. Additionally, future studies should explore psychological and behavioral aspects, such as motivation and adherence, to support more effective and sustainable exercise interventions.

This study demonstrates that aerobic training is effective in reducing body fat, while resistance training excels in increasing muscle mass in obese females. These complementary effects highlight the potential value of combining both exercise types for a more comprehensive approach to body composition improvement. By understanding the strengths and limitations of each exercise modality, these findings can support the development of evidence-based, individualized obesity management programs.

Conclusions

These findings suggest that the two training models have different effects in reducing body fat and increasing skeletal muscle mass in obese women. Body fat reduction was greater in the aerobic training group, while skeletal muscle mass increase was more pronounced in the resistance training group.

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Conflict of Interest

The authors declare that they have no conflicts of interests.

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Використання різних видів фізичних вправ може чинити різноманітний вплив на жирову та м'язову маси у жінок з ожирінням

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 8 с., 3 табл., 5 рис., 46 джерел.

Мета дослідження. Мета цього дослідження полягала в порівнянні впливу аеробних та силових тренувань на покращення композиції тіла жінок з ожирінням.

Матеріали та методи. У цьому дослідженні використовувався справжній експериментальний претест-посттест дизайн із контрольною групою. Загалом 33 жінки з ожирінням віком 23.21 ± 1.36 років, з індексом маси тіла 29.11 ± 3.35 кг/м² і відсотком жирової маси тіла 33.99 ± 2.55 %, було відібрано з числа студенток міста Маланг для участі в програмі аеробних тренувань (Аеробні) та силових тренувань (Силові) тривалістю 8 тижнів. Оцінювання показників композиції тіла на початковому етапі дослідження (переддослідницький) та на завершальному етапі — 8-му тижні (постдослідницький) проводилося із використанням аналізатора складу тіла LN-GS6.5C. Статистичний аналіз застосовувався за допомогою двофакторного дисперсійного аналізу із повторними вимірами, після чого проводився post-hoc тест LSD (найменша значуща різниця) з рівнем значущості 5 %.

Результати. Результати показали, що дельта (Δ) маса тіла, індекс маси тіла, жирова маса тіла та відсоток жирової маси тіла зазнали значного зниження, тоді як після виконання інтервенційних програм з аеробних та силових тренувань спостерігалось суттєве збільшення маси скелетних м'язів порівняно з вихідним рівнем (переддослідницький етап) ($p < 0.05$). Аеробні тренування виявилися ефективнішими у зменшенні жирової маси тіла, тоді як силові тренування були ефективними у збільшенні скелетної м'язової маси ($p < 0.05$).

Висновки. Отримані результати свідчать про те, що обидві моделі тренувань мають різний вплив на зниження рівня жиру в організмі та збільшення маси скелетних м'язів у жінок з ожирінням.

Ключові слова: аеробні тренування, композиція тіла, здоровий спосіб життя, ожиріння, силові тренування.

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Combined Plyometric Trainings and its Effectiveness in Improving Muscle Strength and Power among Male Adolescents

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Abstract

Objectives. This study aimed to evaluate the impact of combined plyometric training on increasing muscle strength and explosive power among male high school students.

Materials and methods. The study was performed using quasi-experimental design with randomized pretest and posttest design. Forty-five students were divided into three groups: SKSQ (squat jump and skater hops); IODJ (ins and outs jump and depth jump); CTRL (conventional training program). The treatments were given three times a week for six weeks. The strength and power of muscle legs were assessed before and after the intervention using Leg Dynamometer and Jump MD. The statistical analysis was conducted using SPSS 29 and GraphdPad Prism.

Results. A paired sample t-test revealed that each group experienced a significant increase ($p < 0.05$), with the most notable improvements in strength ($\Delta = 5.40\%$) and power recorded in SKSQ ($\Delta = 18.33\%$). In contrast, CTRL showed the smallest yet significant gains in both strength and power. From this findings, participants in SKSQ and IODJ demonstrated a greater increase compared to those in the control group.

Conclusions. The results highlighted the effectiveness of combined plyometric trainings in enhancing athletic performance. Further research could explore the underlying mechanisms of these adaptations.

Keywords: muscle power, plyometric training, strength, physical performance, stretch-shortening cycle.

Introduction

Physical fitness is shaped by a variety of key physiological characteristics, with strength being a very important component (Putera et al., 2022). Strength is not only important for daily activities, but also for achieving peak performance in sports that require explosive movements, such as sprinting, jumping, and weightlifting (Alemdaroğlu et al., 2013; Suchomel et al., 2016). In addition to its direct impact on athletic performance, strength training improves other physical abilities, including endurance, speed, and economical movement, by improving muscle and nerve function (Hughes et al., 2018). Regular strength training also increases muscle hypertrophy, strengthens bones and tendons, and increases tendon stiffness, all of which

contribute to greater force production and injury prevention (Brumitt & Cuddeford, 2015).

In addition to strength, power is emerging as another important element that influences athletic performance across a broad spectrum of sports (Marwat et al., 2022). Muscle power allows athletes to do more work in the same period of time or complete the same amount of work faster (Loturco et al., 2015). This ability is very important for high-intensity activities such as sprinting and jumping, as well as for making rapid changes of direction (Saeed, 2013). In particular, the relationship between strength and performance can vary depending on an athlete's level of training, age, and sport, with moderate strength often providing the greatest benefits for skills such as jumping and sprinting. Therefore, integrating targeted strength and power training into a fitness routine is essential to optimize the general health and performance of the specific sport (DeWeese et al., 2015).

Given the importance of both strength and power in sports, there has been considerable interest from researchers

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and coaches in developing effective training programs that can enhance these attributes simultaneously (Wang et al., 2023). One of the widely adopted training methods to improve various aspects of physical performance is plyometric training, which is characterized by explosive movements such as jumps, jumps, and bonds that target large muscle groups and quickly build strength and power (Hariyanto et al., 2022; Wiriawan et al., 2024). Plyometric training applies the principle of the stretch-shortening cycle (SSC), (Pardos-Mainer et al., 2021; Prianto et al., 2024a; Ramirez-Campillo et al., 2020) which activates the neuromuscular system and employs the stretch reflex (Seiberl et al., 2021), leveraging the elastic properties of muscle fibers and connective tissues (Deng et al., 2023), resulting in the production of greater muscular force and power (Davies et al., 2015; Morio et al., 2011).

Over the past few decades, extensive research has documented the benefits of plyometric training (PT), with the majority of studies concluding that it is an effective exercise modality for enhancing various physical attributes (Davies et al., 2015; Oliver et al., 2023). For instance, previous studies demonstrated that PT enhanced sprinting ability, jumping performance, and change-of-direction (CoD) (Aloui et al., 2021), muscle power and strength on soccer players (Bulqini, Achmad, et al., 2023). This improvement is due to the unique biomechanical principles of plyometrics, specifically the stretch-shortening cycle, which improves neuromuscular efficiency and explosive power production. However, plyometric training is not designed to be a standalone method; its benefits are enhanced when integrated with other training programs (Faigenbaum et al., 2007). For instance, combining plyometric exercises with a periodized strength training or balance training has been found to enhance vertical jump performance, muscular power, and proprioception (Chaouachi et al., 2014; Mazurek et al., 2018; Slimani et al., 2016).

Despite these advances, there is still a glaring gap in the literature regarding the effects of combined plyometric exercise programs in particular on adolescent populations. Most previous research has focused on comparing plyometric exercises with conventional endurance exercises or exercise-specific exercises, while the potential synergistic effects of different combinations of plyometric exercises are poorly understood. In addition, the long-term impact and optimal protocols for maximizing strength and power adaptation in adolescents warrant further exploration, especially considering the effects of maturation and growth on exercise response. Therefore, this study aimed to evaluate the effectiveness of two different combinations of plyometric exercises on muscle strength and power in adolescent male students. By addressing these gaps, this study seeks to provide evidence-based recommendations to optimize adolescent athletic development through targeted integrative training strategies.

Materials and methods

Study Participants

This study employed a quasi-experimental design that aimed to evaluate the effects of two different combinations of plyometric exercises on muscle strength and power in

adolescent boys. A total of 45 male junior high school students, aged 13 to 15, were recruited from public junior high schools using systematic random sampling to ensure a representative sample. Inclusion criteria included not having a musculoskeletal injury and no prior experience with structured plyometric exercises. The students were then divided into three groups, each comprised fifteen students: SKSQ (combined squat jumps and skater hops); IODJ (depth jump and ins-and-outs), and CTRL (conventional training).

Study Organization

Each group followed supervised training sessions three times a week over a six-week period, for a total of 18 sessions. Sessions are scheduled on non-consecutive days to provide at least 48 hours of recovery time between training sessions, optimizing adaptation and minimizing the risk of injury (Colberg et al., 2016). The intensity of the exercise was initially set at 60% of the participant's maximum rep (RM) and gradually increased by 10% every two weeks, reaching 80% RM in the final phase. Each session lasts approximately 45 to 60 minutes and includes a standardized warm-up and cool-down period.

Prior the training program, baseline data were collected for all participants. Measurements of height, weight, and body mass index (BMI) were obtained using stadiometers and digital scales calibrated following standard protocols. Meanwhile, pulse rate and blood pressure were measured using a Heart Rate monitor and a sphygmomanometer. After an anthropometric assessment, muscle strength and power were measured using validated instruments. Strength was assessed using Back Leg Dynamometer (Takei Scientific Instruments Co., Ltd.), which measures the maximum isometric strength of the lower leg. Participants conducted three experiments and the highest scores were recorded for analysis. Meanwhile, power was measured using the Jump MD which calculates vertical jump height and power output through force plate technology. Participants performed three countermovement jumps with their hands on their hips to minimize the influence of arm swings, with the best jumps being used for data analysis. All assessments were conducted and evaluated by trained testers.

Statistical Analysis

Data were analyzed using SPSS version 29 (IBM Corp., Armonk, NY) and GraphPad Prism for Mac. Descriptive statistics, including means and standard deviations, were calculated for all variables. Within-group changes from pre- to post-intervention were analyzed using paired t-tests. Between-group differences were assessed using one-way ANOVA, followed by Least Significant Difference (LSD) post-hoc tests to identify specific group contrasts. Statistical significance was set at $p < 0.05$. Assumptions of normality and homogeneity of variance were verified prior to conducting parametric tests.

Results

Table 1 displays the baseline anthropometric characteristics of participants where statistical analysis revealed that the subjects were relatively homogeneous

Table 1. Descriptive statistic of subjects (mean $\pm$ SD)

Variable	SKSQ	IODJ	CTRL
Age (years)	14.65 $\pm$ 0.78	15.30 $\pm$ 0.60	15.12 $\pm$ 0.45
Bodyweight (kg)	45.55 $\pm$ 4.32	43.82 $\pm$ 8.17	41.91 $\pm$ 8.90
Height (cm)	157.18 $\pm$ 8.12	153.91 $\pm$ 8.37	154.55 $\pm$ 8.91
Body mass index (kg/m ²)	18.48 $\pm$ 0.76	18.72 $\pm$ 0.55	17.67 $\pm$ 0.70
Heart rate (bpm)	78.65 $\pm$ 12.88	77.00 $\pm$ 9.09	77.82 $\pm$ 10.12
Systole (mmHg)	109.24 $\pm$ 6.97	105.69 $\pm$ 4.68	107.35 $\pm$ 6.44
Diastole (mmHg)	79.35 $\pm$ 5.43	72.82 $\pm$ 4.05	76.52 $\pm$ 6.16

Table 2. Paired t-test analysis results

Groups		Strength (kg)			Power (watt)		
		T-score	Mean $\pm$ SD	sig.	T-score	Mean $\pm$ SD	sig.
SKSQ	Pre-test	7.26	48.85 $\pm$ 7.30	0.001*	8.96	232.10 $\pm$ 30.14	0.000*
	Post-test		54.25 $\pm$ 6.75			250.43 $\pm$ 31.05	
IODJ	Pre-test	3.92	48.40 $\pm$ 4.50	0.000*	6.24	211.60 $\pm$ 28.58	0.000*
	Post-test		53.00 $\pm$ 4.65			223.15 $\pm$ 31.62	
CTRL	Pre-test	3.10	49.22 $\pm$ 7.07	0.001*	5.28	199.54 $\pm$ 20.18	0.000*
	Post-test		52.79 $\pm$ 6.39			202.05 $\pm$ 21.71	

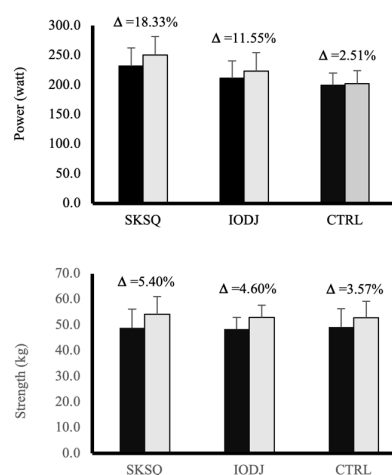
across all groups. The average age between the groups was relatively the same, ranging from 14.65 to 15.30 years. Weight was slightly higher in the SKSQ group (45.55 kg) compared to IODJ (43.82 kg) and CTRL (41.91 kg), while height also showed minimal variation, with SKSQ being the tallest (157.18 cm) and the shortest IODJ (153.91 cm). BMI values are quite consistent, although slightly higher in the IODJ group (18.72 kg/m²). Heart rate was comparable among all groups, ranging from about 77–79 bpm. Notably, the SKSQ group showed the highest systolic (109.24 mmHg) and diastolic (79.35 mmHg) blood pressure, while the IODJ group showed the lowest values for both (105.69/72.82 mmHg). Overall, the two groups were relatively homogeneous in terms of physical and cardiovascular characteristics, with only a slight difference observed.

Table 2 shows the results of paired t-tests evaluating changes in power (kg) and power (watts) before and after the intervention in three groups: SKSQ, IODJ, and CTRL. All three groups showed statistically significant improvements in both strength and power, as indicated by a $p < 0.05$ (marked with *).

The SKSQ group exposed the largest increase, with power increasing from 48.85 $\pm$ 7.30 kg to 54.25 $\pm$ 6.75 kg ($T = 7.26$, $p = 0.001$) and power increasing from 232.10 $\pm$ 30.14 watts to 250.43 $\pm$ 31.05 watts ($T = 8.96$, $p = 0.000$). The IODJ group also increased significantly, with power increasing from 48.40 $\pm$ 4.50 kg to 53.00 $\pm$ 4.65 kg ($T = 3.92$, $p = 0.000$), and power from 211.60 $\pm$ 28.58 watts to 223.15 $\pm$ 31.62 watt ($T = 6.24$, $p = 0.000$). The CTRL group, although not exposed to the special training intervention, also showed a modest but significant increase in strength (49.22 $\pm$ 7.07 kg to 52.79 $\pm$ 6.39 kg, $T = 3.10$, $p = 0.001$) and power (199.54 $\pm$ 20.18 watts to 202.05 $\pm$ 21.71 watts, $T = 5.28$, $p = 0.000$).

All groups demonstrated significant increases in strength after six weeks of their respective training programs ($p < 0.05$), with the SKSQ showing the greatest improvement

($\Delta = 5.40\%$). A similar trend was observed in power, where all groups exhibited significant enhancements ($p < 0.05$), with SKSQ experiencing the highest increase in leg muscle power ($\Delta = 18.33\%$) (Table 2 and 3). Meanwhile, CTRL had the smallest significant increases in both strength (2.51%) and power (3.57%) (Figure 1).

**Fig. 1.** The increases in muscle strength (left) and power (right) after six weeks of combined plyometric training program

These results suggest that the SKSQ and IODJ interventions are effective in improving muscle strength and power, with SKSQ showing the most pronounced improvement. Interestingly, even the control group experienced an increase, which may be due to natural development, general physical activity, or other external factors.

The LSD test indicated significant differences in strength between SKSQ and CTRL ($p = 0.000$) and between IODJ and

Table 3. Between group differences in the changes of strength and power of muscle leg (mean $\pm$ SD)

Group	Δ Strength (kg)	sig.	Δ Power (watt)	sig.
SKSQ	5.77 $\pm$ 2.27		18.71 $\pm$ 2.18	
IODJ	3.68 $\pm$ 1.48	0.000*	14.56 $\pm$ 2.89	0.005*
CTRL	1.91 $\pm$ 1.02		6.71 $\pm$ 1.06	

Table 4. Post-hoc analysis of significant differences in measured variables

Pair-wise Group	Strength	Power
SKSQ IODJ	0.070	0.236
SKSQ CTRL	0.000*	0.000*
IODJ CTRL	0.011*	0.020*

CTRL ($p=0.011$). For power, significant differences were also found between SKSQ and CTRL ($p=0.000$) and between IODJ and CTRL ($p=0.020$) (Table 4).

Discussion

Recent studies have shown that plyometric exercise (PT) significantly improves leg muscle strength and power, with the SKSQ and IODJ groups showing much greater improvements compared to the CTRL group. Specifically, the SKSQ group given combined plyometric exercises between squat jump and skater hop showed the most pronounced improvement in terms of leg muscle strength and power measured at the end of the intervention at week six. These findings underscore the effectiveness of plyometric exercises in stimulating neuromuscular adaptations resulting in increased power production and explosive power (Prianto et al., 2024b). The superior performance of the SKSQ group can be attributed to the dynamic and multi-planar nature of the exercise, which is likely to encourage greater recruitment of fast-twitch muscle fibers and improve the efficiency of stretch-shortening cycles (Maciejczyk et al., 2021). This is in line with previous studies that have reported significant improvements in lower limb strength and power after plyometric training protocols that emphasize vertical and lateral jumping movements (Bulqini, Widodo, et al., 2023). In addition, the substantial increase in power observed is in line with the work of Putera et al. (2023) and Wiriawan et al. (2024) which highlights that plyometric training not only improves muscle strength but also endurance and flexibility, which contributes to overall athletic performance.

In contrast, the IODJ group, which combined depth jump and ins-and-out, also showed significant improvements in strength and power, although their gains were slightly less prominent compared to the SKSQ group. These differences may reflect the different biomechanical demands and neuromuscular stimuli posed by the two training protocols. Depth jumps, known for their high-impact eccentric loads, are effective for developing strength and reactive power, especially in stretch-shortening cycles (Louder et al., 2023). However, the combination with ins-and-outs, which emphasize rapid lateral movements, may have distributed training stimuli across different muscle groups and movement patterns, resulting in a more balanced

but less than maximal increase in isolated force and force size. These findings are in partial contrast to some previous studies that have shown that depth jumps alone result in greater power gain than combined plyometric exercises suggesting that exercise selection and combination may affect training outcomes (Sánchez-Sixto et al., 2021).

The minimal increase in CTRL groups reinforces the idea that conventional training methods without plyometric components may be less effective in eliciting rapid neuromuscular adaptation in adolescent populations. Overall, the results support the growing consensus in sports science that well-structured plyometric training, especially when combining various jump modalities, is essential for optimizing muscle strength and power development in young athletes (Guo et al., 2021; Kobal et al., 2017a; Zhou et al., 2022).

Mechanistically, the effectiveness of PT lies in its exploitation of the stretch-shortening cycle, which allows muscles to store and release elastic energy, thereby enhancing force production and movement efficiency (Davies et al., 2015). Studies have shown that PT can induce beneficial changes in muscle-tendon unit characteristics through neuromuscular regulation, enhancing both strength and flexibility (Hirayama et al., 2017; Silva et al., 2019). The specific combination of exercises used in this study effectively shortened the transition between eccentric and concentric phases, thereby improving jumping ability and leg muscle strength (Louder et al., 2015). Among the experimental groups, SKSQ showed greater improvements due to its focus on single-leg movements, which have been found to be more effective than double-leg exercises for enhancing power and balance (Karimah et al., 2024). This finding is supported by literatures indicating that single-leg plyometric training yields greater explosive force and jump height improvements compared to double-leg training (Ramirez-Campillo et al., 2020).

The observed increases in power among subjects were also linked to exercise intensity. The moderate to high-intensity training employed in this study aligns with previous findings that high-intensity exercises can lead to immediate enhancements in power capacity (Kobal et al., 2017b). Neuromuscular adaptations likely contributed to these improvements, further supporting the effectiveness of PT in enhancing athletic performance (Chelly et al., 2010). Taken together, the results of this study emphasize the importance of exercise specificity and the strategic combination of plyometric modalities in maximizing strength and power outcomes. Future research may benefit from exploring variations in volume, intensity, and recovery periods, as well as long-term adaptations to plyometric training in different adolescent populations.

Conclusions

Plyometric training induces significant adaptations through SSC mechanism, resulting in the increase on strength and power. Given its numerous benefits, PT is recommended as an integral component of exercise programs for individuals. However, the small sample size limits the generalizability of the findings and increases the potential for random errors and bias. Future research should also consider extending the exercise duration beyond six weeks to better observe long-term muscle adaptations.

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Conflict of Interest

The authors declare no conflict of interest.

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Комбіновані пліометричні тренування та їх ефективність у покращенні м'язової сили та потужності серед підлітків чоловічої статі

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 4 табл., 1 рис., 42 джерела.

Мета дослідження. Метою цього дослідження було оцінити вплив комбінованих пліометричних тренувань на підвищення показників м'язової сили та вибухової потужності серед учнів чоловічої статі середньої школи.

Матеріали та методи. Дослідження проводилося із застосуванням квазіекспериментального дизайну з рандомізованим методом претесту та посттесту. Сорок п'ять студентів було розділено на три групи: SKSQ — squat jump and skater hops (присідання з вистрибуванням та бічні стрибки з ноги на ногу, що імітують рухи ковзаняра); IODJ — ins and outs jump and depth jump (стрибки у позиції ноги нарізно-ноги разом та стрибки в глибину); CTRL — conventional training program (традиційна програма тренувань). Тренування проходили тричі на тиждень протягом шести тижнів. Оцінювання показників сили та потужності м'язів ніг проводилося на перед- та постінтервенційному етапах дослідження за допомогою динамометра для ніг та приладу Jump MD. Статистичний аналіз проводився із використанням програмного забезпечення SPSS 29 та GraphPad Prism.

Результати. Т-критерій для парних вибірок встановив, що кожна група зазнала значного підвищення результативності ($p < 0.05$), причому найпомітніші поліпшення спостерігалися в показниках сили ($\Delta = 5.40\%$) та потужності, зафіксованих у групі SKSQ ($\Delta = 18.33\%$). Натомість у групі CTRL відзначено мінімальне, однак суттєве зростання як показників сили, так і потужності. Згідно з отриманими результатами, учасники груп SKSQ та IODJ продемонстрували більший прогрес порівняно з учасниками контрольної групи.

Висновки. Результати підкреслили ефективність комбінованих пліометричних тренувань у підвищенні спортивної результативності. Подальші дослідження можуть бути спрямовані на вивчення механізмів, що лежать в основі зазначених адаптацій.

Ключові слова: м'язова потужність, пліометричне тренування, сила, фізична результативність, цикл розтягування-скорочення.

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The Impact of a 12-Week Structured Yoga Intervention on Flexibility, Balance, and Joint Kinematics in University Athletes: A Quasi-Experimental Study

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Abstract

Objectives. This study aimed to examine the effects of a 12-week structured yoga intervention on flexibility, balance, and joint angles (JA) among university athletes. It was hypothesized that participants undergoing yoga training would show greater improvements across these parameters compared to those following regular sport-specific training alone.

Materials and methods. A quasi-experimental pre-post design was employed, involving 28 male collegiate athletes divided equally into two groups: the Yoga Group (YG, n = 14; handball players) and the Non-Yoga Group (NYG, n = 14; basketball players). The YG underwent bi-weekly 60-minute yoga sessions over 12 weeks in addition to regular training, while the NYG followed only their conventional training. Outcome measures included the Sit-and-Reach (SR) test, Shoulder Flexibility (SF) test, Stork Stand (SS) test for balance, and joint angle (JA) analysis using Dartfish software during three postures: Right Forward Lunge (RFL), Downward Dog (DD), and Chair pose. Normality of the data was confirmed using Shapiro-Wilk tests ($p > 0.05$). Paired t-tests and Welch's t-tests were used for within- and between-group comparisons respectively, with significance set at $p < 0.05$.

Results. The YG showed statistically significant improvements in flexibility and balance: SR increased by +2.1 inches ($p = 0.009$), SF improved by +1.0 inch ($p = 0.025$), and SS time increased by +5.1 seconds ($p = 0.018$). No substantial changes were found in the NYG ($p > 0.05$). Joint angle improvements in the YG included left ankle dorsiflexion during RFL (-7.3° , $p = 0.032$), right hip extension during DD ($+11.4^\circ$, $p = 0.008$), and right knee flexion during Chair pose (-13.2° , $p = 0.011$). The NYG exhibited either negligible or regressive joint angle adaptations.

Conclusions. The findings demonstrate that structured yoga training significantly enhances flexibility, balance, and biomechanical efficiency in collegiate athletes. Integrating yoga into regular athletic conditioning may serve as a valuable adjunct for performance optimization and injury prevention.

Keywords: yoga intervention, flexibility, balance, joint angle kinematics, university athletes.

Introduction

Engagement in sports and physical activity transcends mere physical conditioning—it acts as a powerful catalyst for holistic development, fostering both physical fitness and psychological well-being (Choudhary & Dubey, 2024; Choudhary et al., 2024). Physical activity is essential for daily well-being (Mario & Das, 2022). Physical activity is

a cornerstone of a healthy lifestyle, offering a wide array of benefits for individuals across the lifespan (King & King, 2010). It plays a pivotal role in preventing chronic diseases, enhancing mental well-being, and improving overall quality of life (Kamal & Zulkifli, 2019; Kohl et al., 2013). Flexibility and balance are two critical components that underpin athletic prowess, influencing agility, coordination, and overall performance (Wang et al., 2025). Flexibility, which refers to the range of motion around a joint, enables athletes to execute movements with greater ease and efficiency, thereby reducing the risk of injury (Micheo et al., 2012). Many sports require dynamic movements and quick directional changes, making balance and proprioception essential components

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of being an athlete (Wang et al., 2025). Yoga is a complex philosophy and methodology that evolved over thousands of years in ancient India. Yoga is becoming recognised for its benefits in enhancing both mental and physical well-being (Ghosh et al., 2024; K.S. et al., 2023; Badve et al., 2025). Over recent decades, yoga has become increasingly popular in the West and is now being integrated into healthcare practices (Nayak & Shankar, 2004; Dubey & Choudhary, 2024). Yoga encompasses many physical, mental, ethical, and spiritual practices designed to promote holistic health, well-being, and heightened consciousness (Impett et al., 2006; Ross & Thomas, 2010). The investigation into the effects of yoga on physical and mental well-being has garnered significant attention, leading to a proliferation of studies aimed at quantifying its benefits (Polsgrove et al., 2016). Yoga, an ancient practice integrating physical postures, breathing techniques, and meditation, is recognized for fostering harmony between mind and body (Binorkar, 2014). Yoga practice has been associated with several positive health outcomes, including reductions in blood pressure (Wolff et al., 2013; McDermott et al., 2014), lower blood lipid levels (Pal et al., 2011), decreased body mass index (McDermott et al., 2014), and improved pulmonary function (Parikh et al., 2018; Yadav & Das, 2001). In the realm of sports and fitness, yoga's emphasis on flexibility and balance complements traditional training regimens, potentially reducing the risk of injuries and promoting faster recovery (Paijwar, 2024). Yoga's profound influence on mental health is increasingly recognized, with evidence suggesting its efficacy in mitigating a spectrum of psychological challenges (Hagen et al., 2023). Yoga's multifaceted benefits extend beyond stress reduction and flexibility, potentially enhancing various attributes crucial for athletic performance (Bucea-Manea-Țoniș et al., 2024; Mane et al., 2014). With stronger evidence and deeper insight into its effects on movement performance, yoga has the potential to become a key element of comprehensive training programs, complementing or even replacing some traditional exercise methods (Broad, 2012). Originally rooted in ancient Indian mind-body practices, modern yoga emphasizes physical postures (asanas), breath control, and mindfulness. In athletic contexts, yoga's integrative approach is believed to enhance flexibility, balance, strength, and recovery (Kaur, 2021; Polsgrove et al., 2016). Yoga, an ancient practice, harmonizes physical and mental well-being through a combination of postures, breathing techniques, and focused concentration (Pal et al., 2023).

The physical aspect of yoga involves assuming and maintaining a series of poses, known as asanas, while consciously regulating the breath (Sherman, 2012). These asanas are not merely static stretches but rather active engagements of specific muscle groups, promoting both strength and flexibility (Suryawanshi et al., 2023). The integration of breathing mechanics with an engaged musculoskeletal system during physical poses presents a comprehensive challenge to the body, optimizing the benefits derived from such practices (Chin & Kales, 2019). This approach acknowledges the interconnectedness of breath and movement, enhancing both physical and mental well-being (Pal et al., 2023). Traditional athletic training is characterized by its targeted approach, where specific exercises and activities are employed to enhance distinct components of physical fitness (Lai, 2014). Through

consistent practice, yoga can bring improvements in the alignment of joints involved in kinetic chains, leading to an increased range of motion and enhanced recruitment of muscle fibers (Bucea-Manea-Țoniș et al., 2024). This improved performance is achieved as increased flexibility and reduced muscle tension enhance the stretching of surrounding connective tissues, effectively "loosening" them and decreasing the stress placed on ligaments and joints (Chandler & Brown, 2018). The holistic approach to yoga addresses both physical and mental conditioning, positioning yoga as a powerful modality for athletes aiming to improve their performance (Pal et al., 2023). Its focus on balance, flexibility, strength, endurance, and movement efficiency aligns closely with the multifaceted requirements of athletic training (Pal et al., 2023). Yoga's integration into athletic training regimens has garnered increasing attention due to its potential to augment physical capabilities, particularly in the realms of flexibility and balance, which are foundational elements for success across diverse sports (Polsgrove et al., 2016). Yoga, originating as an ancient discipline, harmonizes the physical, mental, emotional, and spiritual dimensions of practitioners, presenting a holistic approach to wellness that extends beyond mere physical conditioning (Binorkar, 2014; Thangasami & Chandani, 2015). The practice encompasses a variety of components such as physical postures, controlled breathing techniques, relaxation, and meditation (Zhang et al., 2023). A study involving male college athletes demonstrated significant gains in flexibility and balance after a 10-week yoga program. The yoga group showed improvements in sit-reach and shoulder flexibility tests, as well as in balance measured by the stork stand test (Polsgrove et al., 2016). Another study on shooting trainee athletes found similar results, with significant improvements in flexibility and balance after a 6-week yoga intervention. This suggests that even a shorter duration of yoga practice can yield benefits (Iftekhher et al., 2017). Yoga's impact on flexibility and balance extends beyond athletes. A study on female college students during the COVID-19 pandemic also reported significant improvements in these areas after a 16-week yoga intervention (Luo & Huang, 2023). College athletes, operating at the peak of their physical prowess, continually seek avenues to enhance their performance and maintain a competitive edge (Polsgrove et al., 2016). Flexibility and balance, crucial components of athletic capability, significantly influence agility, coordination, and injury prevention (Micheo et al., 2012).

This study aims to evaluate the effects of a 10-week yoga intervention on flexibility and balance among college athletes. Flexibility enhances joint mobility and movement efficiency, while balance is essential for postural stability and neuromuscular control during athletic tasks (Wang et al., 2025; Zech et al., 2010). Though various training methods improve these components, yoga's holistic and low-impact nature offers a unique approach that is underexplored in collegiate sports settings. Prior studies suggest stability-focused programs can enhance athletic performance and reduce injury risk (Song et al., 2020). Therefore, this research investigates whether regular yoga practice can elicit measurable improvements in these key performance variables. This study operates on the hypothesis that a 10-week yoga program will significantly improve flexibility and balance in college athletes.

Materials and Methods

Study Participants

This 12-week preliminary study employed a quasi-experimental pre-post design to evaluate the impact of a structured yoga intervention on selected athletic fitness parameters. Two independent groups of college athletes, engaged in different competitive sports, were assessed. Participant recruitment was facilitated through coordination with collegiate coaches from institutions in the southern region of the country. A total of 30 athletes initially volunteered; however, following inclusion criteria screening, the final sample comprised 28 participants ($N = 28$), with 14 athletes from the handball team ($n = 14$) and 14 from the basketball team ($n = 14$). All participants were free from current musculoskeletal injuries, had no prior extensive experience with yoga, and were medically cleared for physical activity. Before enrolment, participants completed a health history questionnaire and provided written informed consent. To maintain the integrity of the results, participants were blinded to the study's hypothesis. All participants were deemed healthy and capable of safely engaging in the exercise regimen. The study was conducted in strict accordance with the guidelines of the Declaration of Helsinki, ensuring ethical standards were maintained throughout the research process. This adherence underscores our commitment to the ethical treatment and well-being of all participants.

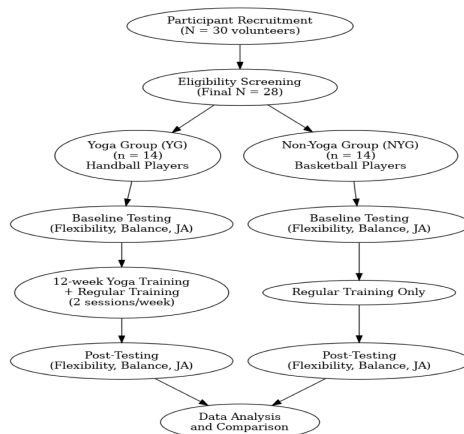


Fig. 1. Flow Diagram

Study Organization

The study involved two groups: the YG (mean age = 19.8 ± 1.05 years) comprised collegiate handball players, while the NYG (mean age = 20.3 ± 1.06 years) included collegiate basketball players. Both groups continued their regular sport-specific training routines, which included common elements like static stretching, resistance training, and aerobic conditioning. Both groups continued to participate in their regular sport-specific training over the 12 weeks. These regular training routines, while largely sport-specific, shared common components such as static stretching, resistance training, and aerobic conditioning (e.g., running). Table 1. Participants' Characteristics (Mean $\pm$ SD)

Table 1. Participants' Characteristics (Mean $\pm$ SD)

Variable	Yoga Group (YG)	Non-Yoga Group (NYG)
Age (years)	19.8 ± 1.05	20.3 ± 1.06
Height (cm)	176.4 ± 5.2	179.1 ± 4.9
Weight (kg)	69.2 ± 6.3	72.5 ± 5.7
BMI (kg/m^2)	22.2 ± 1.4	22.6 ± 1.2

Note: Yoga Group (YG) refers to collegiate handball players who underwent the yoga intervention. The Non-Yoga Group (NYG) refers to collegiate basketball players who followed their regular training regimen. Values represent means $\pm$ standard deviations (SD), indicating variability within each group.

Yoga Intervention Protocol

In addition to their usual training, the YG engaged in supervised yoga sessions twice weekly (Tuesdays and Thursdays) before any other physical activity. Each session lasted 60 minutes, comprising warm-up, asana practice, and cool-down. A certified yoga instructor delivered sessions. Each session lasted 60 minutes and included a standardized sequence of yoga postures (asanas), demonstrated by the instructor and performed synchronously by the participants under supervision. Participants in both groups were instructed to refrain from engaging in any additional training outside of their prescribed routines to ensure consistency and minimize confounding variables. Outcome measures—including flexibility, balance, and joint angle (JA)—were assessed for all participants at baseline (pre-intervention) and immediately following the 12-week intervention (post-intervention).

Procedure

Given that flexibility and balance are foundational components in many sports, these variables were selected to quantify the potential contribution of yoga to athletic performance enhancement (Boehde et al., 2005). Additionally, whole-body joint positioning was assessed to examine angular deviations during various movement tasks, enabling a kinetic analysis of posture and movement through joint angle (JA) evaluations (Latash, 1998). The aim was to determine whether consistent yoga practice could improve biomechanical alignment and functional movement patterns associated with athletic fitness.

Assessments were conducted separately for each group. Baseline testing for the yoga group (YG) was performed two days before the initiation of the intervention, while the non-yoga group (NYG) underwent the same testing protocol one day afterward. Following the completion of the 12-week intervention period, post-testing was conducted one day after the final yoga session for the YG, and subsequently the next day for the NYG. All tests were conducted without a prior warm-up to ensure uniformity across trials.

The assessment battery included six components: (1) Shoulder Flexibility (SF) test, (2) Sit-and-Reach (SR) test, (3) Stork Stand (SS) test for static balance, (4) Right Forward Lunge (RFL), (5) Downward Dog (DD), and (6) Chair pose.

Flexibility was assessed using standardized SF (Bryant, 2010), and SR (Baechle & Earle, 2008) protocols, while

Table 2. Yoga Training Protocol for the Experimental Group (YG)

Week(s)	Session Frequency	Duration	Components	Focus Area
1–2	2/week	60 min	Warm-up: Pranayama, joint mobility Asanas: Tadasana, Vrikshasana, Bhujangasana, Balasana, Adho Mukha Svanasana Cool-down: Shavasana, guided relaxation	Foundational poses, alignment, breathing
3–4	2/week	60 min	Warm-up: Nadi Shodhana, shoulder rolls Asanas: Utkatasana, Trikonasana, Virabhadrasana I & II, Setu Bandhasana Cool-down: Supine twists, Shavasana	Lower limb activation, static balance
5–6	2/week	60 min	Warm-up: Kapalabhati, shoulder mobility Asanas: Downward Dog, Plank, Cobra, Child's Pose, Warrior Flow Cool-down: Forward bends, Anulom-Vilom	Core control, dynamic transitions
7–8	2/week	60 min	Warm-up: Joint loosening Asanas: Chair Pose, Lunge Series, Forward Fold, Bridge Cool-down: Spinal twists, meditation	Flexibility, muscle elongation
9–10	2/week	60 min	Warm-up: Light Vinyasa Asanas: Eagle, Tree, Supine Leg Raises, Bow Pose Cool-down: Breath-hold techniques	Balance, coordination
11–12	2/week	60 min	Warm-up: Meditation, shoulder mobility Asanas: Integrated flow (Sun Salutations, Warrior, Triangle) Cool-down: Yoga Nidra	Postural integration, mind-body awareness

Note- Sessions occurred every Tuesday and Thursday morning throughout the 12 weeks

balance was measured via the Stork Stand test (Coulson & Archer, 2009). For each of these measures, the best of three attempts was recorded to ensure reliability. Video analysis was employed to evaluate JA during the RFL, DD, and chair positions. Participants were instructed to face laterally (with their right side toward the camera) and hold each posture for 10–15 seconds (Latash, 1998; Polsgrove, 2008). Joint angles for the ankle, knee, hip, and shoulder were derived using Dartfish motion analysis software. For unilateral movements like the RFL, joint angles were measured bilaterally. For symmetrical postures such as the DD and chair pose, right-side joint angles were recorded to represent bilateral alignment. These composite measures aimed to provide both quantitative and visual evidence of potential improvements in flexibility, balance, and joint articulation attributable to yoga training. Collectively, the findings from these assessments are expected to inform how yoga may influence key physical performance metrics in collegiate athletes.

Statistical Analysis

Descriptive and inferential statistical analyses were conducted to evaluate changes in flexibility, balance, and joint angle (JA) measures within each group. Due to the use of participants from two distinct sport disciplines, between-group comparisons were limited; therefore, the primary focus was placed on within-group comparisons. Pre- and post-intervention mean values were calculated for all measured variables. Change scores (post-pre) were derived to quantify improvements following the 12-week intervention. To assess the significance of these changes, paired sample t-tests were applied within each group. Additionally, Welch's two-sample t-test was used to compare the change scores between the yoga and non-yoga groups, accounting for unequal variances. All statistical analyses were performed using IBM SPSS Statistics version 26 (SPSS Inc., Chicago, IL, USA), ensuring robust and precise data

handling. Statistical significance was set at $p < 0.05$ for all tests.

Results

The 12-week quasi-experimental study included two assessments—pre- and post-intervention—conducted around 24 structured yoga sessions delivered to the experimental group. A total of 28 male collegiate athletes participated, divided equally between two sports teams: handball (Yoga Group, YG) and basketball (Non-Yoga Group, NYG). The primary outcomes centered on flexibility (sit-and-reach and shoulder flexibility tests), balance (stork stand test), and joint angle measurements during three yoga postures (Right Forward Lunge, Downward Dog, and Chair pose). The Yoga Group exhibited statistically significant improvements across all key variables following the intervention. Specifically, sit-and-reach scores increased by 2.1 inches ($p = 0.009$), shoulder flexibility improved by 1.0 inch ($p = 0.025$), and stork stand balance time increased by 5.1 seconds ($p = 0.018$). In contrast, the Non-Yoga Group did not show meaningful changes in these domains, with slight declines noted across all three tests.

Normality of the data was assessed using the Shapiro-Wilk test. All variables showed p -values greater than 0.05, indicating that the data were normally distributed and suitable for parametric testing (Table 3).

This confirms the assumption of normality required for conducting paired and independent t-tests. The consistency in normal distribution across both Yoga and Non-Yoga groups enhances the reliability of comparative analysis. Therefore, subsequent statistical procedures were deemed appropriate for evaluating intervention effects.

Statistically significant improvements in flexibility—measured through the Sit-and-Reach (SR) and Shoulder Flexibility (SF) tests—and balance—measured through the Stork Stand (SS) test—were observed in the Yoga Group

Table 3. Shapiro-Wilk Normality Test Results

Variable	W-Statistic	p
Sit-and-Reach (YG)	0.939	0.411
Sit-and-Reach (NYG)	0.957	0.668
Stork Stand (YG)	0.982	0.983
Stork Stand (NYG)	0.947	0.517
Shoulder Flexibility (YG)	0.953	0.614
Shoulder Flexibility (NYG)	0.904	0.131

(YG) over the 10-week intervention period [Table 4]. The SR performance for the YG increased from a baseline mean of 21.6 inches (SD = 3.7) to 23.7 inches (SD = 2.4), with a mean improvement of 2.1 inches ($p = 0.009$). Similarly, SF scores improved from -0.2 inches (SD = 2.9) to 0.8 inches (SD = 2.7), reflecting a 1.0-inch gain ($p = 0.025$). The stork stand time also increased significantly, from 13.4 seconds (SD = 6.9) to 18.5 seconds (SD = 7.8), showing a 5.1-second improvement ($p = 0.018$).

Table 4. Comparative Changes in Flexibility and Balance Measures Between Yoga and Non-Yoga Groups

Group	Measure	Change	p	Between-Group, p
YG	Sit-and-Reach (inches)	+2.1	0.009*	0.04*
NYG	Sit-and-Reach (inches)	-0.5	0.27	
YG	Shoulder Flexibility (inches)	+1.0	0.025*	0.14
NYG	Shoulder Flexibility (inches)	-0.9	0.21	
YG	Stork Stand (seconds)	+5.1	0.018*	0.04*
NYG	Stork Stand (seconds)	-3.9	0.14	

Note: YG = Yoga Group; NYG = Non-Yoga Group; $p < 0.05$ indicates statistical significance.

In contrast, the Non-Yoga Group (NYG) showed reductions across all measures. SR scores decreased slightly from 21.2 inches (SD = 2.8) to 20.7 inches (SD = 3.4), a -0.5-inch change ($p = 0.27$). SF performance declined from -1.0 inches (SD = 3.7) to -1.9 inches (SD = 2.8), a -0.9-inch difference ($p = 0.21$). Balance performance, as assessed by the stork stand, also dropped from 21.9 seconds (SD = 8.6) to 18.0 seconds (SD = 9.3), representing a -3.9-second change ($p = 0.14$). Between-group comparisons (YG vs. NYG) revealed statistically significant differences in SR ($p = 0.04$) and SS ($p = 0.04$), indicating that the YG experienced superior gains compared to the NYG by the end of the 10-week intervention.

Whole Body Measures

Within-group comparisons of pre- and post-intervention joint angle (JA) measurements were conducted across three key postures—Right Forward Lunge (RFL), Downward Dog (DD), and Chair Pose—for both the Yoga Group (YG) and Non-Yoga Group (NYG). In the YG, statistically significant improvements were found across multiple joints. During the RFL, a significant increase in left ankle dorsiflexion was observed with a mean change of -7.3° (SD = 10.9; p

= 0.032). In the DD posture, improvements were recorded in right knee extension ($+4.2^\circ$, SD = 6.1; $p = 0.039$), right hip extension ($+11.4^\circ$, SD = 12.5; $p = 0.008$), and shoulder flexion (-6.9° , SD = 9.1; $p = 0.012$). The Chair Pose revealed significant gains in right knee flexion ($+13.2^\circ$, SD = 8.4; $p = 0.011$), indicative of increased lower limb mobility and control. In contrast, the NYG displayed significant but regressive changes, predominantly reflecting compensatory or restricted movement patterns. In the DD position, there was a significant increase in right knee flexion (-10.7° , SD = 11.1; $p = 0.047$), hip flexion (-10.2° , SD = 16.8; $p = 0.049$), and shoulder flexion (-14.9° , SD = 21.5; $p = 0.035$). The Chair Pose showed increased knee flexion (-8.4° , SD = 8.9; $p = 0.018$) and shoulder extension ($+5.7^\circ$, SD = 8.8; $p = 0.048$), suggesting reduced mobility or compensatory shifting during posture maintenance. In table 5 it illustrates the pre-post joint angle improvements in the Yoga Group (YG), with significant gains observed in left ankle dorsiflexion during the R-foot lunge ($p = 0.032$), right knee and hip extension in the Downward Dog pose ($p = 0.039$, $p = 0.008$), and right knee flexion in the Chair pose ($p = 0.011$). These results suggest enhanced lower-limb mobility and functional posture control following yoga intervention.

Table 5. Summary of Pre-Post Joint Angle Changes in the Yoga Group (YG)

Position	Joint	Diff ($^\circ$)	Movement	T-test, p
R-foot lunge	Right knee	-4.8	Flexion	0.12
R-foot lunge	Right hip	-0.9	Flexion	0.48
R-foot lunge	Right shoulder	4.1	Extension	0.23
R-foot lunge	Left knee	-2.3	Flexion	0.53
R-foot lunge	Left ankle	-7.3	Dorsiflexion	0.032
Downward dog	Right ankle	-1.4	Dorsiflexion	0.47
Downward dog	Right knee	4.2	Extension	0.039
Downward dog	Right hip	11.4	Extension	0.008
Downward dog	Right shoulder	-6.9	Flexion	0.012
Chair	Right ankle	-5	Dorsiflexion	0.11
Chair	Right knee	-13.2	Flexion	0.011
Chair	Right hip	-2.1	Flexion	0.44
Chair	Right shoulder	-4.9	Flexion	0.18

Table 6 presents the pre-post intervention changes in joint angles for the Non-Yoga Group (NYG). Unlike the YG, the NYG demonstrated limited or regressive adaptations in joint mobility, many of which may reflect compensatory movement patterns rather than true improvements in flexibility or control. Notably, during the Downward Dog (DD) position, significant increases in right knee flexion (-10.7° , $p = 0.047$) and hip flexion (-10.2° , $p = 0.049$) were observed, suggesting restricted posterior chain mobility, possibly due to tight hamstrings and limited hip extension capability.

Additionally, a significant increase in shoulder flexion (-14.9° , $p = 0.035$) may reflect compensatory overuse of the upper body to offset lower-body stiffness. In the Chair pose, increased knee flexion (-8.4° , $p = 0.018$) and shoulder extension ($+5.7^\circ$, $p = 0.048$) were observed, which may

Table 6. Summary of Pre–Post Joint Angle Changes in the Non-Yoga Group (NYG)

Position	Joint	Diff (°)	Movement	T-test, p
R-foot lunge	Right knee	-2.1	Flexion	0.61
R-foot lunge	Right hip	-0.8	Flexion	0.7
R-foot lunge	Right shoulder	8.7	Extension	0.18
R-foot lunge	Left knee	-5.5	Flexion	0.28
R-foot lunge	Left ankle	1.9	Plantar flexion	0.3
Downward dog	Right ankle	-0.6	Dorsiflexion	0.91
Downward dog	Right knee	-10.7	Flexion	0.047
Downward dog	Right hip	-10.2	Flexion	0.049
Downward dog	Right shoulder	-14.9	Flexion	0.035
Chair	Right ankle	-3	Dorsiflexion	0.09
Chair	Right knee	-8.4	Flexion	0.018
Chair	Right hip	-6.9	Flexion	0.06
Chair	Right shoulder	5.7	Extension	0.048

Table 7. Between-Group Differences in Joint Angles at Post-Intervention (Yoga Group vs. Non-Yoga Group)

Position	Joint	Difference (°)	T-test, p
R-foot lunge	Right knee	3.2	0.29
R-foot lunge	Right hip	0.7	0.46
R-foot lunge	Right shoulder	6.4	0.21
R-foot lunge	Left knee	2.9	0.33
R-foot lunge	Left ankle	9.8	0.012
Downward dog	Right ankle	1.3	0.39
Downward dog	Right knee	14.9	0.009
Downward dog	Right hip	22.3	0.006
Downward dog	Right shoulder	8.1	0.11
Chair	Right ankle	2.2	0.27
Chair	Right knee	4.1	0.13
Chair	Right hip	6	0.09
Chair	Right shoulder	10.9	0.018

indicate instability or reliance on altered mechanics for posture maintenance. These findings suggest that athletes not participating in yoga may adopt biomechanically less efficient strategies during static or semi-dynamic poses, potentially increasing susceptibility to overuse or imbalance-related injuries.

Table 7 displays the post-intervention comparative joint angle differences between the Yoga Group (YG) and Non-Yoga Group (NYG). Significant between-group differences were observed in several key areas, highlighting the superior biomechanical adaptations in the YG following the 10-week yoga intervention. In the R-foot lunge, a significant difference in left ankle dorsiflexion (9.8°, $p = 0.012$) was noted, suggesting enhanced lower-limb flexibility and weight-bearing mobility in the YG. In the Downward Dog, the YG

exhibited significantly greater right knee extension (14.9°, $p = 0.009$) and hip extension (22.3°, $p = 0.006$) compared to the NYG, reflecting improved posterior chain length and control. These postural improvements may translate into better movement efficiency and force distribution during athletic tasks.

Furthermore, in the Chair pose, a significant difference in right shoulder flexion (10.9°, $p = 0.018$) was observed, indicating the YG's superior ability to maintain scapular and upper-body alignment during a complex bilateral task. Overall, the results in Table 4 provide robust evidence that yoga training contributes meaningfully to enhanced joint mobility, symmetry, and functional posture—improvements not seen in the control group. Table 4: Between-Group Joint Angle Differences (YG vs. NYG)

Discussion

This study investigated the impact of a 12-week structured yoga intervention on flexibility, balance, and joint kinematics among collegiate athletes. The findings demonstrated that the inclusion of yoga training significantly enhanced physical performance parameters in the Yoga Group (YG) compared to the Non-Yoga Group (NYG), who engaged solely in conventional athletic training.

The improvements observed in flexibility, specifically in the Sit-and-Reach (SR) and Shoulder Flexibility (SF) tests, indicate that yoga provides additional benefits beyond standard warm-up stretching routines. Although both groups participated in regular static stretching during their respective sports practices, only the YG showed statistically significant gains. These results are consistent with prior literature, which has shown that yoga enhances flexibility through prolonged static holds, mindful breathing, and progressive muscle elongation (McHugh & Cosgrave, 2009; Amin & Goodman, 2014). In contrast, the NYG either showed negligible changes or slight regressions, highlighting the limited efficacy of routine pre-exercise stretching when not supplemented with targeted mobility training. Balance, assessed via the Stork Stand test, also improved significantly in the YG, supporting existing evidence that yoga enhances proprioceptive control and neuromuscular coordination (Zech et al., 2010; Boehde et al., 2005). The lack of significant changes in the NYG, despite participation in skill-based sport-specific drills, suggests that traditional athletic training alone may not sufficiently challenge static balance in a structured or systematic manner. The superior outcomes in the YG underscore yoga's potential as a neuromuscular enhancer capable of stimulating the sensorimotor system through controlled, isometric contractions and dynamic balance postures. Joint angle (JA) analyses provided further biomechanical insights into how yoga contributes to movement efficiency. In the Right Forward Lunge (RFL), YG participants demonstrated significantly increased dorsiflexion of the left ankle, suggesting improved posterior chain mobility and eccentric strength. Conversely, the NYG athletes exhibited no such changes, often adopting more plantar-flexed positions to compensate for limited range of motion. These findings align with previous observations that yoga training fosters improved alignment and muscular balance through full-range joint activation (Clark, 2013; Verkhoshansky, 2009). During the Downward Dog (DD)

posture, the YG showed increases in hip and knee extension and shoulder flexion, reflecting improved hamstring, lumbar, and deltoid flexibility. In contrast, the NYG displayed regressions in these areas, potentially due to compensatory tightness or fatigue accumulation. These divergent adaptations further affirm the corrective and restorative potential of yoga in addressing movement asymmetries and muscular imbalances common in sport-specific training. The divergence in flexibility adaptations observed during the Downward Dog posture between the Yoga Group and the Non-Yoga Group underscores the nuanced impact of yoga on musculoskeletal function (Polsgrove et al., 2016). In the Chair Pose, the YG achieved greater knee flexion while maintaining upright shoulder positioning, suggesting improved core engagement and postural control. In contrast, NYG athletes demonstrated increased shoulder extension, likely as a counterbalancing mechanism to stabilize the center of mass, indicative of weaker lower-limb engagement. This distinction highlights yoga's efficacy in promoting integrated body movement and kinetic chain synergy—attributes essential for athletic performance. The results of the present study align well with previous findings in the literature. For instance, Polsgrove et al. (2016) reported that a 10-week yoga intervention significantly improved flexibility and balance among male college athletes. Their yoga group demonstrated gains in sit-reach ($P = 0.01$), shoulder flexibility ($P = 0.03$), and stork stand balance ($P = 0.05$), along with enhanced joint angles during dynamic yoga positions such as the right foot lunge, downward dog, and chair pose. These improvements mirror the current findings where the yoga group showed significant increases in joint mobility and postural control following 12 weeks of structured yoga training. Similarly, Luo and Huang (2023) found that a 16-week yoga program significantly enhanced flexibility and balance in female college students, particularly during the pandemic when access to conventional training facilities was limited. Participants showed measurable gains in balance (e.g., single-limb stance and Romberg test) and flexibility (e.g., sit-and-reach and groin mobility), whereas the control group saw no change. This supports the broader generalizability of yoga's benefits across different genders and contexts, reinforcing its relevance as a holistic training modality. Furthermore, the findings of Iftekhher and Rahaman (2017) provide additional support, demonstrating that even a short-term, 6-week yoga intervention significantly improved flexibility ($P = 0.017$) and balance ($P = 0.004$) in shooting trainees. The consistent improvements across different populations, durations, and sporting backgrounds emphasize yoga's potential to enhance core physical parameters essential for athletic performance. The increases in hip and knee extension alongside shoulder flexion within the Yoga Group suggest enhanced flexibility in the hamstrings, lumbar region, and deltoid muscles, potentially stemming from the sustained stretching and postural alignment inherent in regular yoga practice (Zhang et al., 2023). Regular yoga practice may promote a more balanced musculoskeletal system, mitigating the risk of injury and optimizing athletic performance (Holtzman & Beggs, 2013). The results of the present study align with the findings of Dubey and Choudhary (2024), who reported significant improvements in back flexibility ($\Delta = 3.20 \pm 0.95$ cm) and lumbar flexion ($\Delta = 1.50 \pm 0.75$ cm) among female college students following a six-week Surya Namaskar intervention,

further supporting the positive role of yoga-based practices in enhancing musculoskeletal flexibility and spinal mobility. The findings of the present study are further supported by Choudhary et al. (2025), who demonstrated that a six-week perturbation-based balance training program significantly improved dynamic stability in university basketball players, highlighting the value of neuromuscular training in enhancing balance and postural control. Similar to our yoga-based intervention, their results confirm the efficacy of structured training protocols in promoting athletic balance and reducing performance-related asymmetries. The study by Balaji et al. (2024) supports the present findings by demonstrating that a six-week Surya Namaskar intervention significantly improved back flexibility and lumbar flexion in male college students, thereby reinforcing the role of structured yoga practices in enhancing musculoskeletal function and overall physical well-being. Although yoga is widely recognized for its positive effects on flexibility and balance, similar improvements can also be achieved through other exercise modalities such as traditional stretching and strengthening programs. Further, a study by Waza and Deol (2025) complements the current findings by emphasizing yoga's positive role in influencing musculoskeletal parameters. Their comparative analysis revealed that yoga practitioners demonstrated moderate improvements in bone mineral density and body composition, reinforcing the current study's evidence that structured yoga interventions contribute to flexibility, posture, and overall physical health. Research by Gothe and McAuley (2016) demonstrated that both yoga and conventional exercise routines are equally effective in enhancing functional fitness parameters like balance and flexibility in older adults. This highlights that while yoga is a valuable approach, it is among several effective strategies available for improving these physical capacities.

Together, these studies substantiate the observed improvements in the present investigation and suggest that regular integration of yoga into athletic training regimens can meaningfully augment flexibility, balance, and joint functionality, particularly in sports demanding precision and mobility. Collectively, the results of this study provide compelling evidence that yoga can serve as a potent adjunct to conventional athletic training by improving flexibility, balance, and neuromuscular coordination. The integration of yoga into collegiate sport programs may offer a holistic training modality that addresses both physical and mental dimensions of athlete performance.

Conclusion

This 12-week quasi-experimental study demonstrated that integrating a structured yoga intervention into the training routines of collegiate athletes significantly enhanced key physical performance parameters, particularly flexibility, balance, and joint mobility. The Yoga Group (YG), composed of handball players, exhibited notable improvements across all measured variables, including sit-and-reach, shoulder flexibility, stork stand balance, and joint angles in functional postures such as the right foot lunge, downward dog, and chair pose. In contrast, the Non-Yoga Group (NYG), comprised of basketball players engaged in regular sport-specific training without yoga, showed negligible or regressive changes, underscoring the

added value of yoga beyond conventional athletic routines. These findings affirm that yoga, when consistently practiced under structured guidance, can serve as a powerful adjunct to traditional training regimens, addressing biomechanical alignment, neuromuscular coordination, and functional mobility. By promoting muscular balance, postural symmetry, and enhanced proprioceptive control, yoga contributes to more efficient movement patterns that are vital for both performance enhancement and injury prevention. The study's results align with and extend the current literature on yoga's efficacy, highlighting its versatility and applicability across diverse sporting contexts. The observed gains, particularly in joint angle control and static balance, suggest that yoga can help athletes develop the foundational movement quality necessary for optimal performance in dynamic sports. Future investigations should aim to explore long-term adaptations, delve into sport-specific performance metrics, and include physiological measures such as VO_2max , muscle activation patterns, or stress biomarkers (e.g., cortisol) to comprehensively understand yoga's multidimensional impact. Given the positive outcomes observed, athletic programs at the collegiate level should consider incorporating yoga into their training protocols to foster well-rounded physical development.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Вплив 12-тижневої інтервенції зі структурованої йоги на гнучкість, рівновагу та кінематику суглобів університетських спортсменів: Квазіекспериментальне дослідження

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 11 с., 7 табл., 1 рис., 57 джерел.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу 12-тижневої інтервенції зі структурованої йоги на гнучкість, рівновагу та суглобові кути (СК) серед університетських спортсменів. Було висунуто гіпотезу, що учасники, які виконують тренування з йоги, продемонструють кращі результати за зазначеними параметрами порівняно з тими, хто займається виключно регулярними тренуваннями, специфічними для певного виду спорту.

Матеріали та методи. Застосовано квазіекспериментальний пре-пост дизайн дослідження, до якого було залучено 28 студентів-спортсменів чоловічої статі, розподілених порівно на дві групи: група, що займалася йогою (YG, n = 14; гандболісти), та група, що не практикувала йогу (NYG, n = 14; баскетболісти). Група YG протягом 12 тижнів двічі на тиждень додатково до звичайних тренувань відвідувала 60-хвилинні заняття з йоги, тоді як група NYG дотримувалася виключно свого звичайного режиму тренувань. Критерії оцінювання показників включали тест на вимірювання загальної гнучкості тіла при згинанні тулуба вперед, сидячи на підлозі з витягнутими вперед руками ("Sit-and-Reach test", SR), тест на гнучкість плечей (SF), тест на рівновагу у позиції «Лелека» ("Stork Stand test", SS) та аналіз суглобових кутів (СК) з використанням програмного забезпечення Dartfish у трьох положеннях: випад вперед правою ногою (RFL), поза «Собаки мордою вниз» ("Downward Dog", DD) та поза «Стільця». Нормальність даних було підтверджено за допомогою критеріїв Шапіро-Вілка ($p > 0.05$). З метою порівняння внутрішньогрупових та міжгрупових показників використовувалися парні t-критерії та t-критерії Велча відповідно, з рівнем значущості $p < 0.05$.

Результати. Група YG продемонструвала статистично значуще поліпшення гнучкості та рівноваги: SR збільшився на +2.1 дюйма ($p = 0.009$), показник гнучкості плечей покращився на +1.0 дюйма ($p = 0.025$), а час виконання тесту на рівновагу у позиції «Лелека» збільшився на +5.1 секунди ($p = 0.018$). У групі NYG істотних змін встановлено не було ($p > 0.05$). Поліпшення показників суглобових кутів у групі YG включали дорсифлексію лівої гомілки під час виконання випаду вперед правою ногою (-7.3° , $p = 0.032$), розгинання правого стегна під час виконання пози «Собаки мордою вниз» ($+11.4^\circ$, $p = 0.008$) та згинання правого коліна під час виконання пози «Стільця» (-13.2° , $p = 0.011$). У групі NYG спостерігалися незначні або регресивні адаптації суглобових кутів.

Висновки. Результати дослідження показують, що структуровані тренування з йоги сприяють значному покращенню гнучкості, рівноваги та біомеханічної ефективності у студентів-спортсменів. Інтеграція йоги до регулярних спортивних тренувань може слугувати цінним доповненням для оптимізації результативності та запобігання травматизму.

Ключові слова: інтервенція з йоги, гнучкість, рівновага, кінематика суглобових кутів, університетські спортсмени.

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Analyzing Muscle Damage (CK-MM) and Recovery of Muscle Strength between Non-Professional and Professional Basketball Athletes

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Basketball is considered to be one of the most popular sports. Besides recreational training sessions, basketball lovers as non-professional athletes often perform competitions like basketball athletes, characterized by high intensity. However, the biological changing is limited.

Objectives. This study aimed to analyze the differences between basketball lovers as non-professional athletes and professional athletes regarding their blood CK-MM levels and their recovery of muscle strength.

Materials and methods. The present study was an analytical observation, involving adult males subjects (19-29 years old) divided into 2 groups: non-professional athletes (NP, n=9) and professional athletes (PA, n = 9). The blood CK-MM levels were measured using the ELISA method. The push, pull, leg, and back muscle strength were assessed with a dynamometer. The data were obtained 3 times: before (pre), 1 hour after the game (post1), and 1 day after the game (post2).

Results. The results showed that there was a higher muscle strength in the PA group compared with the NP group ($p < 0.05$). However, in both groups, the recovery of all muscle strength, except push muscle, did not occur after 1 day of the game. This was linear with the level of blood CK-MM in both groups, with a higher level of CK-MM in NP. Nevertheless, there was insignificance between groups ($p > 0.05$).

Conclusions. The findings indicate that non-professional athletes have lower strength and a higher trend of blood CK-MM level compared to professional athletes. However, the recovery of muscle strength and the changing pattern of CK-MM are similar between the two groups, which reveals that active people, such as non-professional athletes, have a good adaptation as athletes.

Keywords: muscle strength, CK-MM, basketball, athletes, healthy lifestyle.

Introduction

Basketball is a dynamic sport played by two opposing teams that continuously attack and defend to achieve victory (Salafi et al., 2023). According to Gottlieb et al. (2014), basketball involves horizontal movements such as sprinting and changing direction, as well as vertical movements such as jump shots, rebounds, and dunks. These characteristics require players to possess optimal physical capacities,

particularly muscular strength, endurance, and reaction speed. To improve performance in basketball, it is essential to focus on physical fitness, both in terms of health-related and skill-related components. Physical fitness in basketball is critical in supporting performance and preventing injury. It is influenced by various factors such as physiological conditions, physical demands during the game, and recovery after the game (Putera et al., 2023; As'ad et al., 2022; Ayubi et al., 2022). According to Yewen et al. (2024), basketball players need to have high levels of muscular strength, particularly in the arms, legs, and back, to support movement efficiency during games.

A tight competition schedule and the high intensity of the game increase the risk of fatigue and decreased

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performance. Muscle fatigue can impair the effectiveness of muscle contractions and increase the risk of injury (Goud et al., 2023). Athletes with well-trained muscles tend to be more resistant to fatigue due to better neuromuscular and metabolic adaptations (Schoenfeld et al., 2017). Basketball movements generally involve dynamic muscle contractions, including both concentric and eccentric contractions. Muscular strength plays a key role in various movements during the game, such as jumping, landing, sprinting, shooting, dribbling, throwing, and passing (Ferraz et al., 2021). These movements involve isotonic contractions, consisting of both concentric and eccentric phases. Eccentric contractions, which occur when a muscle lengthens while generating force, contribute significantly to mechanical stress and microtrauma in muscle tissue. This activity can lead to skeletal muscle damage and delayed onset muscle soreness (DOMS) (Hedayatpour et al., 2018). Acutely, eccentric-induced muscle damage is estimated to account for 10–55% of all sports-related injuries. The proportion varies by sport, with approximately 11% in rugby, 16% in running, and 18% in basketball (Maffulli et al., 2015). Martinez et al. (2022) also state that sports involving dominant eccentric contractions carry a high risk of muscle damage. Such microscopic injuries trigger the release of biochemical markers such as creatine kinase (CK), particularly the CK-MM isoform derived from skeletal muscle. Creatine kinase (CK-MM) is a commonly used biomarker to detect muscle damage following physical activity. CK-MM levels increase significantly after high-intensity exercise, especially activities involving eccentric contractions (Baird et al., 2012). Lieber (2018) reports that CK-MM levels increase within 45 minutes after ergometer testing and return to baseline within 24 hours in trained athletes, whereas in untrained individuals, elevated CK-MM levels may persist for up to six days. This demonstrates differences in muscle recovery capacity and adaptation between trained and untrained individuals.

Research by Damas et al. (2016) also reports that repeated resistance training-induced muscle damage can acutely reduce muscular strength, although it may promote hypertrophic adaptation in the long term. Similarly, Subagio et al. (2025) find that the high-load low-repetition (HLLR) group experiences greater microtrauma compared to the low-load high-repetition (LLHR) group, as the HLLR protocol involves lifting heavier loads. In the context of competitive sports, it is important to understand how muscle strength and muscle damage biomarkers change before and after competition. To date, the differences in muscle damage levels and muscular strength before and after basketball matches between non-professional (NP) and professional athletes (PA) remain unclear.

Based on the above background, this study aims to analyze the differences in muscle damage markers (CK-MM), as well as the muscle strength of the arms, legs, and back, between non-professional athletes and professional athletes.

Materials and Methods

Participants

The subjects recruited for this study were males aged 19 to 29 years old. This study received ethical approval from

the Research Ethics Committee of the Faculty of Medicine, Universitas Airlangga, with certificate number 138/EC/KEPK/FKUA/2025.

This study was an analytical observational study. The subjects consisted of two groups: the non-professional athlete group (NP) and the professional athlete group (PA). All subjects signed informed consent forms and agreed to participate in the study. Each group initially included 10 participants. However, after conducting an outlier analysis using SPSS based on CK-MM levels, one participant from the professional group was identified as an outlier, likely due to non-compliance, and was therefore dropped from the study. Consequently, one participant from the NP group was removed through a random draw. Thus, each group consisted of 9 participants.

Procedure and Protocol Test

Before the matches began, all subjects were not allowed to perform moderate- or high-intensity exercise from 24 hours before the match until the study was completed. This restriction was implemented to avoid bias in blood biomarker results. The basketball matches were played 5 vs. 5 according to FIBA standards (PA vs. PA; NP vs. NP). Subjects performed a 5-minute warm-up under the supervision of an instructor before the match started. Each basketball game consisted of four quarters (4 x 10 minutes), lasting a total of 40 minutes. There was a 1-minute break between quarters. The matches were officiated by three referees: the head referee, the second referee, and the scorekeeper. The court used for the games was standardized for basketball competitions and maintained at a room temperature between 20 and 22°C.

Anthropometric measurements were taken before the match to assess body weight and height, which were subsequently used to calculate body mass index (BMI). Height was measured using a SECA 213 portable stadiometer, while body weight was measured using a TANITA Bc545n. BMI was calculated by dividing weight by height squared (kg/m^2). Arm muscle strength was measured using a shoulder and arm dynamometer (Dynamometer, TTM, Tokyo, Japan), while leg and back muscle strength was assessed using a back and leg dynamometer (Takei 5002 BACK-D, Type 3, Takei, Japan). All muscle strength measurements were recorded in kilograms (kg). Venous blood samples (3 cc) were collected from the cubital vein to measure CK-MM levels and analyzed using the Human CKM Enzyme-Linked Immunosorbent Assay (ELISA) Kit from BT LAB, reported in U/L. Blood sample analysis was conducted at the research laboratory of Universitas Airlangga Hospital. Muscle strength measurements and blood sampling were conducted at three time points: before (pre), 1 hour after the game (post1), and 1 day after the game (post2).

Statistical Analysis

Data analysis was performed using SPSS software. The data analysis included descriptive statistics to determine characteristics consisting of means and standard deviations before the match, one hour after, and one day after the match. Normality was tested using the Shapiro-Wilk test; homogeneity was tested using Levene's test. Differences between the NP and PA groups were analyzed using the

independent t-test or Mann-Whitney test. Differences across time within groups were analyzed using repeated measures ANOVA.

Result

The characteristics of the participants are presented in Table 1. The average age of the NP group was younger than that of the PA group; however, this difference was not statistically significant ($p = 0.59$). The NP group had a mean age of 20.89 ± 2.20 years, while the PA group had a mean age of 23.89 ± 3.33 years. Based on Table 1, no significant differences were found between the NP and PA groups in terms of age or body mass index (BMI). Therefore, both groups can be considered to be at equivalent stages of physiological growth.

Table 1. Participant characteristics

Variables		NP group (n = 9)	PA group (n = 9)	p*
Age (years)	mean $\pm$ SD	20.89 ± 2.20	23.89 ± 3.33	0.59
	Median	20	25	
BMI (kg/m ²)	mean $\pm$ SD	24.30 ± 2.70	24.45 ± 2.68	0.95
	Median	24.14	24.92	

Note: BMI = body mass index; NP = non-professional athletes; PA = professional athletes; *T-independent test or mann whitney test

The results of the CK-MM levels analysis between the NP and PA groups are presented in Figure 1. The average CK-MM level in the NP group before the match was 247.90 ± 42.90 U/L, while in the PA group it was 246.52 ± 37.12 U/L. One hour after the match, the CK-MM level in the NP group decreased to 234.45 ± 23.24 U/L, whereas in the PA group it decreased to 211.23 ± 30.56 U/L. One day after the match, the CK-MM level in the NP group slightly increased to 240.31 ± 48.55 U/L, and in the PA group it rose to 225.49 ± 31.04 U/L. The results of the repeated measures test on CK-MM levels between the NP and PA groups showed no significant difference ($p = 0.148$).

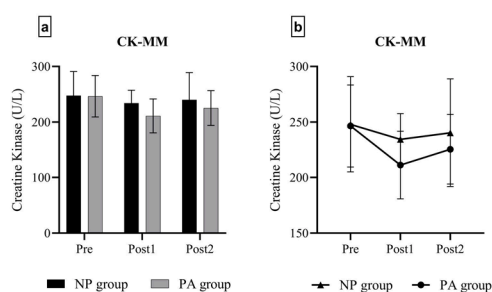


Fig. 1. The concentration of CK-MM in each group (a) and the changing of CK-MM (b). Pre = before the game; Post1= 1 hour after the game; Post2= 1 day after the game

Figure 2a presents arm muscle strength measured using a push dynamometer in the NP and PA groups. The average push muscle strength before the match was 25.38 ± 8.58 kg in the NP group and 40.55 ± 10.56 kg in the PA group. One hour after the match, the NP group showed an increase to 26.50 ± 9.94 kg, and the PA group increased to

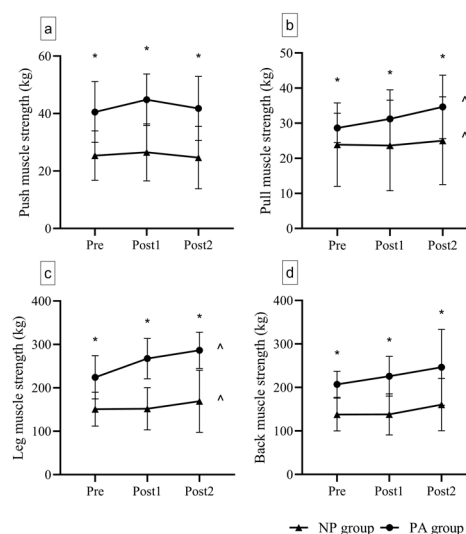


Fig. 2. The changing of muscle strength. Pre = before the game; Post1= 1 hour after the game; Post2= 1 day after the game. *sig. diff between groups at the same time ($p < 0.05$), t independent test or mann whitney test. ^sig. diff in the same group due to different time ($p < 0.05$), repeated measures ANOVA

44.55 ± 10.56 kg. However, one day after the match, push muscle strength decreased to 24.66 ± 10.86 kg in the NP group and to 41.77 ± 11.15 kg in the PA group. The pattern of change in push muscle strength was similar in both groups, with an increase one hour after the match followed by a decrease one day after the match. Repeated measures tests showed no significant differences over time, but there were significant differences between groups in the overall results of the push muscle strength measurements ($p_{\text{time}} = 0.150$; $p_{\text{group}} = 0.002$). Based on the results of post hoc analysis, there were significant differences between the two groups before the match, one hour after the match, and one day after the match ($p = 0.004$, $p = 0.001$, $p = 0.005$ respectively).

The mean arm muscle strength measured using a pull dynamometer (Figure 2b) in the NP and PA groups before the match was not significantly different (NP = 23.88 ± 11.88 kg; PA = 28.66 ± 4.18 ; $p = 0.272$). One hour after the match, the NP group had an average of 23.66 ± 12.93 kg, while the PA group increased to 31.22 ± 8.31 kg ($p = 0.160$). One day after the match, the NP group increased to 25.00 ± 12.53 kg and the PA group increased to 34.66 ± 9.04 kg ($p = 0.079$). The repeated measures test showed a significant difference over time in pull muscle strength between the two groups ($p = 0.013$).

Figure 2c shows that there was a significant difference in pre-match leg muscle strength between the NA and PA groups, where the PA group showed higher mean values than the NP group (NP = 150.88 ± 39.04 kg; PA = 224.33 ± 49.97 kg). One hour after the match, the NP group had an average of 151.88 ± 48.64 kg, whereas the PA group increased to 267.44 ± 46.54 kg. One day after the match, leg muscle strength in the NP group increased to 169.00 ± 71.37 kg, and in the PA group to 286.41 ± 41.95 kg. Repeated measures tests showed significant differences over time ($p = 0.019$) and between groups ($p < 0.001$) in the overall leg muscle strength measurement results. Based on the result of post hoc analysis, there were significant differences between the

two groups before the match, one hour after the match, and one day after the match ($p = 0.003$; $p = 0.001$; $p = 0.002$ respectively).

Figure 2d shows the back muscle strength in the NP and PA groups. The average back muscle strength was higher in the PA group than in the NP group. The back muscle strength before the match was 137.94 ± 37.66 kg, while in the PA group it was 207.11 ± 30.11 kg. One hour after the match, the NP group did not experience significant changes, with a strength of 138.11 ± 47.26 kg, while the PA group increased to 225.77 ± 45.68 kg. One day after the match, back muscle strength in the NP group increased to 160.66 ± 60.18 kg, and in the PA group to 246.35 ± 87.07 kg. The repeated measures test showed no significant difference over time, but there were significant differences between groups in the overall results of the back muscle strength (p time = 0.148; p group < 0.001). Based on the results of post hoc analysis, there were significant differences between the two groups before, one hour, and one day after the match ($p = 0.001$; $p = 0.001$; $p = 0.015$ respectively).

Discussion

This study aims to analyze the differences in muscle damage markers as well as the muscle strength of the arms, legs, and back between non-professional athletes and professional athletes.

Creatine kinase

Creatine kinase (CK-MM) serves as an indicator for detecting muscle damage caused by physical activity (Baird et al., 2012). The CK-MM levels measured before the match, one hour after, and one day after show no significant differences between the NP and PA groups. In this study, the average CK-MM level decreases one hour after the match. According to Clarkson & Hubal (2002), this decline may result from increased blood flow after the match, which accelerates the clearance of CK-MM from the bloodstream. However, this decrease is temporary, as CK-MM levels typically peak within 24–72 hours following physical activity (Brancaccio et al., 2007). In the current study, no peak in CK-MM levels is observed even 24 hours post-match. Gutenbrunner (2000) compares CK-MM responses between trained and untrained individuals using an ergometer test. The results show that the untrained group exhibits increased CK-MM levels, while the trained group does not demonstrate a significant rise. In this study, the NP group trains three times per week, while the PA group trains ten times per week. Both groups are considered trained individuals, which may explain why CK-MM levels do not significantly increase 24 hours after the match.

Arm, Leg, and Back Strength

The results of arm muscle strength during the push movement, measured before, one hour after, and one day after the match, indicate that the PA group demonstrates higher strength compared to the NP group. The push movement is essential in basketball for activities such as dribbling, shooting, passing, and rebounding. According to Murach & Bagley (2016), regular training increases muscle hypertrophy. In this study, the NP group trains three times

per week, while the PA group trains ten times per week. Therefore, push strength is greater in the PA group. On average, push strength increases one hour after the match. This finding aligns with Finlay et al. (2022), who state that high-intensity activities such as dribbling, passing, and shooting enhance neuromuscular activation, leading to a temporary increase in muscle strength. Pull strength in the arm muscle also increases after the match in both the NP and PA groups. According to Lambrich & Muehlbauer (2025), this occurs because trained athletes tend to have higher fatigue tolerance after competition. Since both groups in this study consist of trained individuals, arm muscle pull strength increases after the match in both NP and PA athletes.

Leg muscle strength plays a crucial role in basketball, particularly for running and jumping. The results of this study show that leg and back muscle strength measured before, one hour after, and one day after the match is higher in the PA group. This finding is consistent with the study by Schoenfeld et al. (2017), which explains that intensive and well-structured strength and endurance training improves muscle strength and hypertrophy. Increases in leg and back strength after the match are observed in both groups. This improvement is likely due to the effect of regular training in enhancing intermuscular activation and coordination, which contributes to faster muscle recovery (Franchi et al., 2017; Peake et al., 2016). Monica (2015) also states that trained athletes tend to have greater fatigue tolerance after competition. Since both groups in this study consist of trained individuals, leg and back strength increases after the match in both NP and PA athletes.

Conclusions

This study concludes that professional athletes (PA) have greater muscle strength compared to non-professional athletes. The muscles recovery is not occurred after one day of competition, except push muscle. This pattern of muscles recovery is similar to the pattern of CK-MM levels, however insignificantly between groups. This indicates that the non-professional athletes obtain a good effect as active people. Nonetheless, further research is needed to better understand the physiological response mechanisms and the effects of prolonged training for safety.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Аналіз пошкодження м'язів (КК-ММ) та відновлення м'язової сили серед непрофесійних та професійних баскетболістів

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

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Історія питання. Баскетбол вважається одним із найпопулярніших видів спорту. Окрім рекреаційних тренувальних сесій, поціновувачі баскетболу, які не є професійними спортсменами, часто беруть участь у змаганнях, типових для баскетболістів, що характеризуються високою інтенсивністю. Однак біологічні зміни є обмеженими.

Мета дослідження. Це дослідження мало на меті проаналізувати відмінності між поціновувачами баскетболу як непрофесійними спортсменами та професійними спортсменами щодо рівня КК-ММ (креатинкіназа м'язового ізоферменту, що знаходиться в скелетних м'язах) в крові та відновлення м'язової сили.

Матеріали та методи. Представлене дослідження проводилося у формі аналітичного спостереження, в якому взяли участь дорослі представники чоловічої статі (віком 19–29 років), розподілені на 2 групи: непрофесійні спортсмени (НП, n = 9) та професійні спортсмени (ПС, n = 9). Визначення рівня КК-ММ у крові здійснювалося із використанням методу імуноферментного аналізу (ІФА). Оцінювання показників сили відштовхування, тяги, м'язів ніг і спини проведено за допомогою динамометра. Отримання даних здійснено тричі: безпосередньо перед грою (переддослідницький етап), через 1 годину після гри (постдослідницький етап1) та через 1 день після гри (постдослідницький етап2).

Результати. Результати показали, що в групі ПС показник м'язової сили був вищим порівняно з групою НП (p < 0.05). Однак в обох групах відновлення всієї м'язової сили, крім сили м'язів під час відштовхування, не спостерігалось через 1 день після гри. Це було лінійно пов'язано з рівнем КК-ММ в крові в обох групах, причому рівень КК-ММ був вищим у групі НП. Проте значущої різниці між групами не встановлено (p > 0.05).

Висновки. Результати дослідження свідчать про те, що непрофесійні спортсмени мають нижчі показники сили та вищий рівень КК-ММ у крові порівняно з професійними спортсменами. Однак відновлення м'язової сили та зміна патерну КК-ММ є подібними в обох групах, що вказує на належну адаптацію до занять спортом активних осіб, як-от непрофесійних спортсменів.

Ключові слова: м'язова сила, КК-ММ, баскетбол, спортсмени, здоровий спосіб життя.

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Defining Authenticity of the Y Balance Test Implemented by an Intellectual Programmed Tool in Inclusive Physical Education

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Abstract

Objectives. The study aimed to investigate the authenticity of the Y Balance Test for the lower quarter (LQYBT), implemented by a developed intelligent programmable tool for students after blast TBI with acoustic trauma.

Materials and methods. At the theoretical level, analysis, synthesis, systematization, and generalization were used, while at the empirical level, technical modeling, applied programming, a pedagogical experiment using the LQYBT, and mathematical statistics were employed. The study sample consisted of first-year students after mild blast TBI with acoustic trauma.

Results. The results are presented in a developed intelligent programmable tool for LQYBT implementation. The development of the tool involved using the MPU-6050 GY-521 module, which is placed into the sole of the footwear intended to perform LQYBT. Another element of the developed tool is “intelligent vectors”, which are placed on the axes of LQYBT execution and consist of a matrix of pressure sensors. This matrix registers pressure changes at the points of contact for the student's foot and automatically identifies loss of balance, foot movement, or errors related to changes in body position. Integrating information from the MPU-6050 GY-521 module and “intelligent vectors” is facilitated by using the Arduino Uno board comprising the ATmega328P microcontroller as the main processor and the ATmega16U2 microcontroller for communication with a PC via a USB port. The board recognizes signals and transmits them sequentially to a PC, where they are processed by the developed software and displayed on the screen. Wireless infrared communication is used to transmit the signal. A key feature of this smart tool is the use of artificial intelligence. The reliability and validity indicators of LQYBT after blast TBI with acoustic trauma, when the results are recorded by the teacher, correspond to the “average” and “acceptable” levels. When using the developed tool, they reached the “high” level.

Conclusions. The findings suggest that using an intelligent programmable tool for the implementation of LQYBT is a powerful means of monitoring the current state of balance in students after blast TBI with acoustic trauma in real time, its permanent analysis and forecasting, for making timely and adequate management decisions regarding the rehabilitation program in the process of inclusive physical education.

Keywords: students, blast TBI with acoustic trauma, physical education, inclusion, control, test authenticity, digitalization.

Introduction

Every day in Ukraine, the number of people who have become disabled due to war-related injuries is growing. In the context of Russia's war against Ukraine, the prevalence of blast traumatic brain injury (TBI) among both military personnel and civilians is reaching unprecedented levels, as the impact of the widespread use of the latest high-energy weapons is very significant for the entire body (Dzyak et al., 2023; Denby et al., 2020).

Blast TBI complicated by acoustic trauma is particularly common as a result of armed damage caused by blast waves (Akin et al., 2022; Li, 2023; Sudhakar et al., 2020). Acoustic trauma, particularly in veterans, is a factor in the increase in disability, with an annual rate of 13-18% (Aural Blast/Injury Acoustic Trauma and Hearing Loss, 2018).

At the same time, blast TBI with acoustic trauma has a cumulative effect, which has quite significant consequences for the health of victims (Alkathiry et al., 2019; Haarbauer-Krupa et al., 2021; Du et al., 2023). Despite this, timely and adequate care for blast TBI is crucial for preventing consequences and ensuring a speedy recovery (Blennow et al., 2016; Misyura, Ruban, & Mishin, 2022; Mullally, 2017).

Currently, an increasing number of individuals with blast TBI are participating in higher education. In the near future, given the current reality of Russia's ongoing military aggression in Ukraine, the rehabilitation of students of war injuries is becoming increasingly relevant (Blavt et al., 2024; Byshevets et al., 2024). The restoration of students' health during the learning process is ensured by the use of the potential of inclusive physical education (PE) in this process (Giuriato, 2023; Ben Rakaa, Bassiri, & Lotfi, 2025).

Given the need for sustainable development of the education sector to keep up with modern narratives, there's a clear need to modernize inclusive PE, considering the steady increase in the number of students with disabilities after blast TBI in higher education institutions.

Analysis of recent research and publications. Research (Bodnar, & Sofinsky, 2024) has shown that despite the war, Ukraine continues to implement important changes in the field of inclusive PE. It is indisputable (Keles, ten Braak, & Munthe, 2022) that quality education should contribute to improving health, and that good health is a prerequisite for obtaining a proper education (Lieberman, Houston-Wilson, & Grenier, 2024; Blavt et al., 2024).

The issue of the quality of inclusive PE, which in higher education provides a rehabilitation function for students with disabilities, is the subject of a number of studies (Blavt, & Gurtova, 2024; Giuriato, 2023; Navas-Bonilla et al., 2025). After analyzing research initiatives (Lund, & Kirk, 2019; Kuntjoro et al., 2022; López-Pastor et al., 2012), it was found that monitoring the process PE provides valuable information about its effectiveness, helping to optimize the process of restoring health. According to the information (Akin et al., 2022; Mucha, Fedor, & DeMarco, 2018; Sudhakar et al., 2020), the consequences of changes that the brain undergoes during blast TBI can manifest themselves in various ways.

Many authors have addressed the issue of rehabilitation after a blast TBI (Shvets et al., 2020; Ng, & Lee, 2019; Perkins et al., 2022). According to the literature (Reilly, 2021; Misyura, Ruban, & Mishin 2022; Leland et al., 2016), the effects of blast TBI can lead to serious disorders in the

body and affect a person's working capacity, legal capacity and socialization, so it is important that treatment and rehabilitation are supervised.

Numerous studies have been devoted to the effects of blast TBI on the body (Kovacs, Leonessa, & Ling, 2014; Sepehry, Schultz, & Mallinson, 2024). First of all, acoustic trauma, which is defined as trauma caused by an acoustic blast wave, is considered by specialists (Shvets et al., 2020) to be a multiple trauma that falls under the concept of blast TBI. Motor disorders and sensory dysregulation are considered (Alkathiry et al., 2019; Mucha, Fedor, & DeMarco, 2018) to be the main types of disorders after blast TBI with acoustic trauma.

In particular, problems with hearing and the vestibular apparatus (acoustic trauma) (Alkathiry et al., 2019; Akin, & Murnane, 2011; Murray et al., 2019), vision, memory impairment, spatial coordination, attention, concentration, and reaction, and later with the musculoskeletal system and difficulty performing movements (Akin et al., 2022; Du et al., 2023; Denby et al., 2020).

Numerous studies focus on the role of assessment and testing in ensuring the effectiveness of PE (Baumgartner et al., 2015; Kuntjoro et al., 2022; López-Pastor et al., 2012). It has been proven (Lieberman, Houston-Wilson, & Grenier, 2024; González-Rivera et al., 2023) that systematic objective monitoring is a tool for avoiding bias and ensuring progress toward achieving goals in this process. Researchers see the solution to this issue in the creation of auxiliary tools that can provide reliable and rapid analysis of research parameters (Goodwin et al., 2003; Lund, & Kirk, 2019).

The purpose of the study research is to investigate the authenticity of the Y_Balance_Test for the lower quarter (LQYBT), implemented by a developed intelligent programmable tool for students after blast TBI with acoustic trauma.

Materials and Methods

Research Methods

The methodology of our study covers a two-level (theoretical and empirical) complex of scientific knowledge methods/The theoretical level of the study was practice-oriented while complying with the requirements of consistency and using methods of analysis, synthesis, induction, deduction, and interpretation.

At the empirical level, the following research methods were used: technical modeling to create an experimental prototype of the device, applied programming, pedagogical experiment, and mathematical statistics.

The choice of LQYBT for conducting a pedagogical experiment was guided by the need for simplicity of execution, practicality in use for measuring dynamic equilibrium, the absence of the need for complex equipment, and the possibility of repeated repetition.

The test procedure. The LQYBT has the student stand on one leg while reaching out in 3 different directions with the other lower extremity (Fig. 1). They are anterior, posteromedial and posterolateral. The maximal reach is measured by reading the distance at the edge of the reach indicator closest to the subject to the nearest half centimeter. The limb being tested is the stance limb (Physiopedia: Y Balance Test).

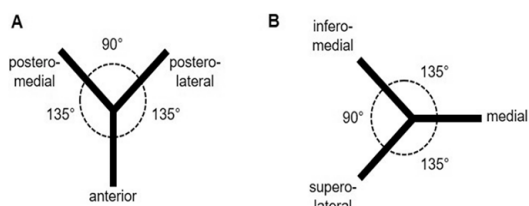


Fig. 1. Scheme of the LQYBT (Schwiertz, Beurskens, & Muehlbauer, 2020)

When performing LQYBT, the following should be observed: the supporting leg should not be lifted off the floor; the hands should be kept on the hips; the extended leg should not touch the floor; the standardization of returning to the starting position should be observed (Kattilakoski et al., 2023).

Study Participants.

The study sample consisted of first-year students (24 male) after mild blast TBI with acoustic trauma who were involved in the study from Lviv Polytechnic National University, Lviv State University of Physical Culture named after Ivan Boberskyj, Kamianets-Podilskyi National Ivan Ohienko University, Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy.

Given that the authenticity of the test depends on the qualitative characteristics of the study sample (Baumgartner, et al, 2015), the inclusion criteria were set at 18-25 years of age and no impairment of vital body functions. The exclusion criterion was previous experience with LQYBT, to avoid the influence of the learning effect.

All students underwent a medical examination before the start of testing and signed a letter of consent to participate anonymously in the testing.

The study was planned and carried out following the principles of bioethics set forth by the World Medical Association (WMA-2013) in the Helsinki Declaration «Ethical Principles of Medical Research Involving Humans» and UNESCO in the «General Declaration on Bioethics and Human Rights».

Research Organization

The experiment was carried out in the process of inclusive PE. The essence of the comparative study was to conduct testing and record the results in two ways. In the first case, all testing and data collection was carried out by one teacher, and the distance was measured with a ruler. In the second case, the testing was carried out using a specially developed intelligent programmable control device.

Each student in the study sample was informed and familiarized in detail with the testing procedure, given specific instructions for performing the test, visually demonstrated, and provided explanations regarding incorrect performance.

Three directions of reach: anterior, posteromedial, and posterolateral, were to be performed. The students performed three attempts in the specified directions of reach,

To prove the authenticity of the test, its reliability and validity were determined. The conclusions of the study are based on a comparative analysis of the numerical values of the reliability and validity of the LQYBT, implemented using various measurement tools.

Statistical Analysis

The formation of generalized results and conclusions of the study involved the use of mathematical statistics methods. Correlation analysis was used to establish the level of authenticity, namely the numerical values of reliability and validity (Baumgartner et al, 2015).

Mathematical statistics methods were used to process, analyze, and interpret the experimental data using SPSS Version 22.0 (IBM Corporation).

Results

As proven (Shumway-Cook, & Horak, 1986), the predominant sensory signal for balance control is somatosensory information from the feet in contact with the supporting surface. Therefore, these positions should be taken into account when controlling stability in different conditions.

The results of the empirical stage of the study are presented in a developed intelligent programmable tool for LQYBT implementation. A compact and lightweight MPU-6050 GY-521 module was used to create the LQYBT implementation tool.

The MPU-6050 GY-521 module consists of a 3-axis accelerometer and a 3-axis gyroscope (Mykytyuk et al., 2024). This module is used to determine the position in space and angular displacements that indicate a loss of balance, such as a body tilt of more than 30°, which occurs during the performance of LQYBT. The module was placed in the sole of the footwear used to perform LQYBT (Fig. 2).

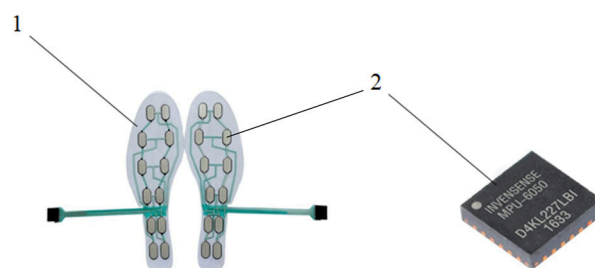


Fig. 2. Special footwear with a built-in MPU-6050 GY-521 module: 1 – special footwear, 2 – MPU-6050 GY-521 module

Another element of the developed tool is «intelligent vectors» which are placed on the axes of the LQYBT and consist of a matrix of pressure sensors located on the surface (Politanskyi et al., 2024). This matrix registers pressure changes at the points of contact of the student's foot and automatically identifies loss of balance, foot movement, or errors related to changes in body position.

To integrate information from the MPU-6050 GY-521 module and «intelligent vectors» the development uses an Arduino Uno board, which consists of an ATmega328P

microcontroller as the main processor and an ATmega16U2 microcontroller for communication with a PC via a USB port. The board can be powered via USB or from an external power source. The type of source is selected automatically.

Importantly, the ATmega328 microcontroller on the board has a built-in bootloader, which allows new programs to be loaded into it without the need for an external programmer. The software for the intelligent tool was developed in the Delphi environment, which is used to run the test and determine the quality of its performance.

LQYBT using the developed intelligent programmable tool is implemented as follows (Fig. 3). The student puts on a special footwear with a built-in MPU-6050 GY-521 module and takes the starting position in the center of the vectors on which the pressure sensor matrices are located. The signals generated in the module and pressure sensors when the student performs the test task are transmitted to the Arduino Uno board. The signals are recognized by the board and transmitted sequentially to a PC, where they are processed by software and displayed on the screen using a user interface. Wireless infrared communication is used to transmit the signal.

A key feature of this intellectual tool is its ability to classify, plan, and predict the inclusive PE process based on test control data. To do this, it uses artificial intelligence technology, specifically neural networks for processing, such as sorting and searching large amounts of test data.

The analysis of the data obtained can be supplemented by visual tracking of the test process using a camera, for example, using a Raspberry Pi with an OpenCV module,

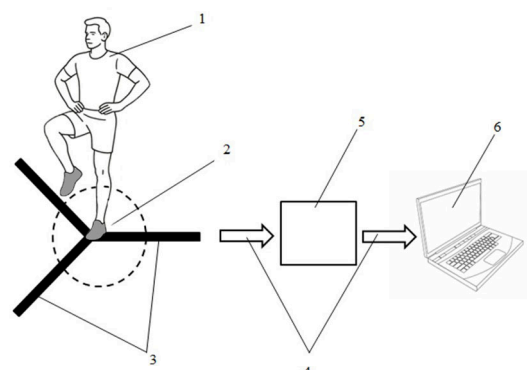


Fig. 3. Scheme of LQYBT implementation using an intelligent programmable tool: 1 – student, 2 – special footwear with a built-in MPU-6050 GY-521 module, 3 – “intelligent vectors” with a matrix of pressure sensors, 4 – infrared communication lines, 5 – Arduino Uno board, 6 – PC

which provides real-time recording of deviations in the performance of the test task. We visualize the results through a mobile application developed on the Blynk platform. The data can be presented in the form of graphs, tables, or 3D models of student movement.

A prominent characteristic of the developed control system is its ability to operate in energy-saving mode, which is extremely important in modern domestic realities.

The final stage of the study involved determining the numerical values of the authenticity indicators of LQYBT,

Table 1. Authenticity of the of the LQYBT for students after blast TBI with acoustic trauma when measured by a teacher (n = 24)

Test tasks		Statistical parameters and measurement results						
		X	S	As	Me	V(%)	reliability (rtt)	validity (rtt)
posteromedial	r	91.1	5.0	0.13	89.9	31.3	0.447	0.211
	l	93.3	6,7	0.17	91.5	28.3	0.482	0.203
posterolateral	r	86.7	4.2	0.19	83.1	29.5	0.510	0.205
	l	81.7	6.8	0.21	78.4	30.3	0.560	0.198
anterior	r	69.1	4.2	0.49	67.7	31.5	0.484	0.191
	l	65.5	4.7	0.26	62.9	28.6	0.412	0.218

*Note: r – right leg, l – left leg, X – arithmetic mean, S – standard deviation, Me – median, V – coefficient of variation

Table 2. Authenticity of the of the LQYBT for students after blast TBI with acoustic trauma using the developed intelligent programmable tool (n = 24)

Test tasks		Statistical parameters and measurement results						
		X	S	As	Me	V(%)	reliability (rtt)	validity (rtt)
posteromedial	r	95.7	5.7	0.18	91.9	22.3	0.876	0.501
	l	92.1	5.6	0.11	86.2	24.1	0.812	0.488
posterolateral	r	91.4	4.9	0.15	87.3	22.6	0.902	0.492
	l	88.9	3.3	0.13	86.4	26.1	0.897	0.512
anterior	r	72.5	6.2	0.49	69.2	21.5	0.879	0.465
	l	69.1	3.1	0.26	64.4	24.3	0.913	0.517

*Note: r – right leg, l – left leg, X – arithmetic mean, S – standard deviation, Me – median, V – coefficient of variation

implemented using various measurement tools. The results are presented in Table 1, 2.

The reliability and validity indicators of LQYBT after blast TBI with acoustic trauma, when the results were recorded by the teacher, corresponded to the “average” and ‘acceptable’ levels. When using the developed intelligent programmable tool, the numerical values were significantly higher and reached the “high” level.

Discussion

Our study is based on the assertion that ensuring the effectiveness of student rehabilitation after blast TBI in the process of inclusive PE requires constant monitoring of the state of recovery in dynamics and analysis of this process (Lund, & Kirk, 2019; Misyura, Ruban, & Mishin, 2022). Therefore, we support scientific approaches (Kuntjoro et al., 2022; López-Pastor et al., 2012; González-Rivera et al., 2023) that objective monitoring of inclusive PE is the basis for the effectiveness of the methods used and their timely correction. Information has been expanded (Blavt, et al., 2023; Perkins et al., 2022) on the importance of periodically assessing parameters that have been damaged as a result of injuries, in particular blast TBI (Li, 2023; King et al., 2014; Mucha, Fedor, & DeMarco, 2018). This confirms the ideas (Lieberman, Houston-Wilson, & Grenier, 2024; López-Pastor et al., 2012) about using assessment results as a basis for improving and individualizing the rehabilitation process and physical education itself.

At the same time, we agree with the view (King et al., 2014; Salafi et al., 2023; Yilin et al., 2024) that the testing process should eliminate the influence of human factors as much as possible to meet the requirements of impartiality. It is test reliability that is recognized as a factor in the objectivity of data on the effectiveness of the control process (Marchenko, Ivashchenko, & Kupreichenko, 2023; Ng, & Samsudin, 2024; Putro et al., 2025).

Our scientific research expands on the data (Asongu, Orim, & Nting, 2019; Navas-Bonilla et al., 2025; Mokmin, & Rassy, 2024) on ensuring the effectiveness of the inclusive educational process, seeing the solution to this issue in constructive technological solutions and applied programming.

In line with the results of our scientific research (Gao, Guan, & Tan, 2025; Goodwin et al., 2003) on the transformation of the inclusive physical education process and its implementation in accordance with the individual needs of each student, based on our previous studies (Blavt et al., 2024), which are based on the development of automated control systems using the high-tech capabilities of modern digital technologies.

In our study, we took into account information that scientists see the restoration of balance as the key to improving quality of life and maximizing the recovery of lost functions (Reilly, 2021; Misyura, Ruban, & Mishin, 2022). Our study expands on existing findings on vestibular effects after blast TBI (Haarbauer-Krupa et al., 2021; Blavt et al., 2024), which is a new area of assessment and research that may contribute to predicting long-term outcomes. At the same time, testing postural stability is becoming increasingly important for assessing motor function after TBI (Guskiewicz, 2001; Merritt et al., 2017; King et al., 2014).

Our study is based on information (Schwartz et al., 2019) about the widespread use of LQYBT to control

dynamic balance in various populations. The list includes: individuals with chronic ankle instability (Olmsted et al., 2002); military personnel with closed head injuries and barotrauma (Shvets et al., 2020); healthy early adolescent female athletes (Greenberg et al., 2019); student-athletes and general college students (Engquist et al., 2015); in healthy adults (Powden, Dodds, & Gabriel, 2019); healthy trained and untrained youth (Schwartz, Beurskens, & Muehlbauer, 2020); male collegiate soccer players (Plisky et al., 2009); in adolescent athletes (Linek et al., 2017); in healthy female and male adolescents from grade 6 to 11 (Schwartz et al., 2019); in high school athletes (Smith et al., 2018); in recreationally active healthy adults (Bubić, & Kozinc, 2023).

Despite a significant list of studies on establishing the authenticity of LQYBT, no study has sought to establish the level of authenticity of LQYBT for students after blast TBI with acoustic trauma. We were guided by information (Plisky et al., 2021) about the need to take into account the characteristics of the study sample when interpreting the LQYBT test results. This is consistent with the opinion that before a test can be used in practice, its reliability in a specific population should be determined (Maricot et al., 2024; Merritt et al., 2017; Marchenko, Ivashchenko, & Kupreichenko, 2023).

Conclusions

The process of transforming inclusive education is now inevitable, given the trend toward an increase in the number of students with disabilities due to the ongoing hostilities in Ukraine. In order to meet today's challenges, higher education institutions must do everything possible to ensure the accessibility of all areas of the educational process so that students with disabilities are provided with the conditions for proper rehabilitation of their health during the learning process.

Seeing the solution to the issue of ensuring the effectiveness of the rehabilitation process for persons with disabilities in constructive and technological solutions and applied programming, we ensure the modernization of this process and its implementation on a scientifically sound basis, following the individual needs of each student after blast TBI with acoustic trauma.

The use of an intelligent programmable tool for the implementation of LQYBT is a powerful means of monitoring the current state of balance of students after blast TBI with acoustic trauma in real time, its permanent analysis and forecasting, for making timely and adequate management decisions in the process of inclusive PE. This is confirmed by the numerical values of the authenticity characteristics of LQYBT when the results are recorded by an intelligent programmable tool. In contrast, when the results are recorded by a teacher, the level of authenticity of LQYBT is significantly lower.

Thus, through objective real-time monitoring, high-quality calculations, and data analytics, we ensure the objectivity of monitoring students with post-blast TBI in the process of inclusive PE.

Conflict of Interest

If the authors have any conflicts of interest to declare.

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Визначення автентичності тесту «Y баланс» реалізованого інтелектуальним програмованим інструментом у інклюзивному фізичному вихованні

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Реферат. Стаття: 9 с., 2 табл., 3 рис., 66 джерел.

Мета дослідження полягала у дослідженні автентичності тесту Y- балансу для нижньої частини тіла (LQYBT), реалізованого розробленим інтелектуальним програмованим інструментом для студентів після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою.

Матеріал та методи. На теоретичному рівні використано аналіз, синтез, систематизації, узагальнення; емпірично-му – технічного моделювання, прикладного програмування, педагогічного експерименту з використанням LQYBT, математичної статистики. Досліджувана вибірка складалась із 24 студентів 1-го курсу після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою.

Результати представляємо у розробленому інтелектуальному програмованому інструменту для реалізації LQYBT. Для створення інструменту використали модуль MPU-6050 GY-521, який розміщено у підшві взуття для виконання LQYBT. Ще одним елементом розробленого інструменту є «інтелектуальні вектори», які розмістили на осях виконання LQYBT і які складаються з матриці датчиків тиску. Така матриця реєструє зміни тиску в точках дотику ноги студента та автоматично ідентифікує втрату рівноваги, пересування ноги або помилки, пов'язані зі зміною положення тіла.

LQYBT з використанням розробленого інтелектуального програмованого інструменту реалізується наступним чином. Студент одягає спеціальне взуття з вбудованим модулем MPU-6050 GY-521 та займає вихідне положення у центрі «інтелектуальних векторів», на яких розміщено матриці датчиків тиску. Сигнали, які виникають у модулі та у датчиках тиску при виконанні тестового завдання студентом, передаються на плату Arduino Uno. У платі сигнали розпізнаються та передаються послідовно на ПК, де обробляються програмним забезпеченням та відображаються на екрані з допомогою програмного інтерфейсу користувача. У розробці використано технологію штучного інтелекту, а саме нейромережі для обробки, як от сортування та пошуку великих обсягів даних тестування.

Отримані показники надійності та валідності LQYBT після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою, у разі фіксації результатів викладачем, відповідні рівню «середній» та «прийнятний». У разі використання розробленого інструменту – досягли рівня «високий».

Висновки. Використання інтелектуального програмованого інструменту для реалізації LQYBT є потужним засобом моніторингу поточного стану рівноваги студентів після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою, в режимі реального часу, його перманентного аналізу й прогнозування, для прийняття своєчасних і адекватних управлінських рішень у інклюзивному фізичному вихованні.

Ключові слова: студент, вибухова черепно-мозкова травма, акуборотравма, фізичне виховання, інклюзія, контроль, автентичність тесту, цифровізація.

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Review Article

The Influence of Circuit Training in Improving Technical Skills and Physical Performance of Young Football Players: A Systematic Review

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Abstract

Objectives. This study aimed to examine the effect of circuit training (CT) on improving technical skills and physical performance for adolescent soccer players, and to provide an understanding of the effective application of CT.

Materials and methods. In this study, the selection process was carried out using the PRISMA filter. Four databases were used to search for research sources that cover circuit training in improving technique performance and physical performance or fitness. The databases used include ScienceDirect, Scopus, Google Scholar, and PubMed, encompassing publications from 2015 to 2025.

Results. The literature review used in this study identified 6 articles suitable for further analysis after a rigorous selection from a total of 878 articles. Among the 6 articles obtained, 5 focused on improving physical performance and 1 article focused on enhancing technical skills. In its implementation, it is necessary to pay attention to the frequency of training, training intensity, training duration, and variation in training. The review results indicate that CT has proven to be effective in improving technical skills and physical performance in youth soccer players.

Conclusions. Based on the analysis results, CT has been shown to improve the physical condition of teenage soccer players, such as physical fitness in preventing injuries, speed, agility, muscle endurance, explosive power, and players' techniques such as passing, shooting, dribbling, interceptions, tackles, and takeovers. To enhance physical aspects, there are training models that can be used, namely HICT, MICT, IT, and CT, while to improve techniques, the CT training model can be applied. It is hoped that the findings of this study can open opportunities for other researchers to apply it to technical skills.

Keywords: circuit training, technical skills, physical performance, literature review, youth soccer players.

Introduction

Circuit training (CT) is a popular methodology in fitness and health programs, as well as in sports, because its modulation induces physiological benefits, such as strength, power, and cardiovascular-respiratory adaptation (Anitha et al., 2018; Giménez & Gomez, 2019; Marín-Pagán et al., 2020). CT consists of several training posts that have specific training objectives that can be adjusted with the appropriate intensity and time that has been tailored to support relevant training (Amna Saleh Team, 2024; Mahalingam et al., 2024; Tereshchenko et al., 2021). In youth football, this type of training is not only useful for improving physical capacity

in terms of endurance, speed, and strength, but also has the potential to be implemented in the development of technical skills (Aaron Francis Niles, 2023; Muez Tsegay et al., 2021; Păun et al., 2022). With the right modifications, CT can be used on the basic skill elements in soccer, where basic skills are also an important component of soccer performance.

The biological and psychological development of adolescents is important in the effort to develop young football players and must be tailored to their age while taking into account the principles of appropriate training (Arenas et al., 2024; Fomichenko & Ivanov, 2023; Wik, 2022). At the age of 12–15 years, players experience rapid growth accompanied by an increase in their capacity to learn movement (Leyhr et al., 2018).

CT plays an important role in enhancing the physical performance of football players. This method allows athletes to train various aspects of physical fitness in one training

session, such as endurance, strength, agility, and speed, all of which are essential in football (Anitha et al., 2018; Badawi & Nasrulloh, 2023; Ferley et al., 2020). This improvement has a positive impact on the players' ability to play optimally in matches with consistent performance. In addition, CT has also been proven to enhance the technical performance of football players, as demonstrated by the research conducted by (Farooque et al., 2023; Sáez de Villarreal et al., 2015) that the CT methodology can improve dribbling and shooting skills. CT is a promising approach because it has flexible characteristics and can be easily adapted to various goals and needs in training programs (Păun et al., 2022).

In improving the performance of football players, it is important to design the right training model that meets the specific needs of the game (Pacholek & Zemková, 2020; Shao, 2024). An effective training model must be able to combine physical exercises and techniques in a balanced and efficient manner, so that each player can achieve their optimal performance (Sautov & Tyshchenko, 2024). Models like CT, which can be customized to physical and technical needs, provide an efficient and practical alternative (Anitha et al., 2018; Farooque et al., 2023). In addition, choosing the right training model can help prevent excessive fatigue and optimize the body's recovery after training or competitions (Biró et al., 2023; Looft & Frey-Law, 2020).

The advantage of CT is that it can create efficient training programs and relatively short time usage (Ratajczak et al., 2024; Salierno et al., 2021). With an organized structure, each training post can focus on one type of skill or specific fitness component, allowing for high functional repetition, which is important in the movement learning process (Ardanari et al., 2023; Beihul et al., 2023; Sakthivel & Rangaraj, 2025). In addition, CT can be easily modified according to the player's skill level and the specific goals of the training session (Alim et al., 2024; Kurkure S & Gharote G, 2024).

CT has been widely used in various sports to improve physical aspects, however research specifically examining the application of CT to enhance the technical performance of young soccer players is still very limited. Most existing research actually focuses more on improving physical conditions, and there is a lack of research that includes technical aspects in the application of CT methods. Until now, no systematic studies have been found that specifically review the role of CT in developing technical skills and physical fitness of young football players. With the advantages of CT and the lack of research on the impact of CT on aspects of Engineering, the goal of this research is to analyze existing evidence to discuss how CT can enhance the technique and physicality of young football players and how to implement it effectively. This finding is expected to provide a reference for researchers in the future and to offer guidance for trainers to develop more effective and sustainable training programs.

Materials and Methods

Research Design

This research employs a comprehensive strategy in data collection for a systematic review, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework as outlined in the literature (Page et

al., 2021). The PRISMA systematic review methodology has become a standard in various fields of research for systematically screening, evaluating, and synthesizing literature (Kwao Dawson et al., 2023; Mahadi, 2023; Shivhare & Shunmugasundaram, 2023). This design was chosen because PRISMA provides a systematic and transparent framework for reporting the results of systematic reviews. The application of inclusion and exclusion criteria is carried out meticulously to ensure that the selected studies have high relevance and quality. This study utilizes 4 databases to find research sources that cover circuit training in improving technique performance and physical performance or fitness. The databases used include Science Direct, Scopus, Google Scholar, and Pubmed. Data source searches using the Boolean Operators 'AND' and 'OR' to systematically obtain sources, the following keywords were used in this research ("circuit training") AND (Technical performance and physical performance) AND (young football player OR youth soccer player).

Inclusion and exclusion criteria

To be included in this review, the research must meet the specific criteria outlined below:

Inclusion Criteria:

- Participants: Young football players aged between 8-18 years.
- Intervention: Circuit training.
- Outcome: Technical performance and physical performance.
- Research design: Randomized Controlled Trial and Quasi-Experimental Experiment.
- Publication Year: The last 10 years or from 2015-2025.

Exclusion Criteria:

- The source does not use English.
- No complete text is available.
- Other sports are excluded.
- Review articles are not used.

Data Extraction

A total of 878 studies were initially extracted from electronic database sources, of which 825 studies were excluded based on their titles. A total of 54 studies were screened for extraction from which 36 others were excluded for not being suitable upon further review, ultimately filtering down to 18 inclusion criteria, and finally leaving 6 studies that met the inclusion criteria. Data extracted from this study and its summary is presented in Table 1, which includes authors & years, article title, sample size, training method, research method, and research results.

Results

In the source search process, a total database of 878 studies was obtained for review. 6 studies remained after meeting the inclusion and exclusion criteria. The final studies included were analyzed narratively. This procedure is depicted in figure 1 using the PRISMA flow diagram (Page et al., 2021).

Based on the research results in Table 1, it shows that there are five articles that found that CT has a significant

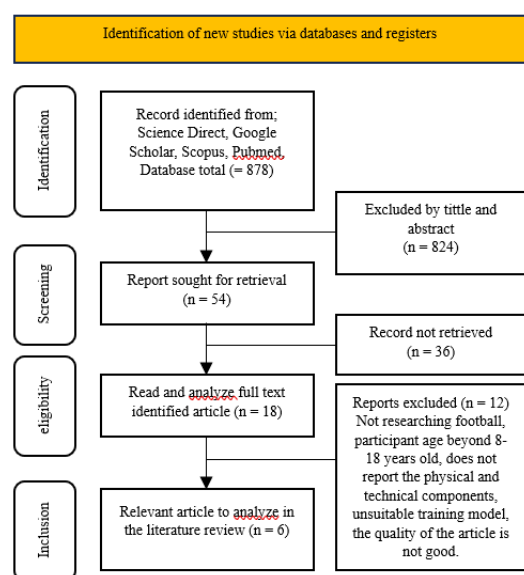


Fig. 1. The article selection process uses PRISMA guidelines

effect on improving physical performance, and one article has an effect on improving technical skills. This proves that there are still few studies on CT concerning technical skills compared to physical performance.

Discussion

In designing a training program, there are important aspects that need to be considered, including frequency, intensity, duration, and variety. The age of the players should also be taken into account when designing the training program; otherwise, the players will be at risk of injury. The training program for youth soccer players will be different from that of professional players, as during adolescence the player's muscle growth is in a developmental stage, thus requiring adjustments to training that are safe and enjoyable. Here are the aspects that need to be considered.

Training Frequency

The frequency of training is one of the key factors in developing physical aspects and techniques for youth football

Table 1. Research features that are examined for review

Author and years	Article Title	Sample Size	Training Method	Research Method	Result
Muez Tsegay et al., 2021	Effect of Varied Intensity of Football Specific Circuit Training on Agility, Speed and Explosive Strength among U-17 Football Players in Ethiopia	Sample Size total sample N = 60, N1 = 20, N2 = 20, N = 20, average age 15-17 Years.	HICT vs MICT	quasi-experimental	The HICT group showed a significant difference from the MICT group in agility, explosive strength, and speed.
Zein et al., 2020	The effect of short period high-intensity circuit training-modified FIFA 11+ program on physical fitness among young football players	N = 39 young soccer players aged 15-19 years. N = 20 subjects in the EXP group and N = 19 in the CON group.	HICT	quasi-experimental	This research shows that the modified FIFA 11+ HICT and standard FIFA 11+ can enhance physical fitness components in reducing the risk of injury. The modified FIFA 11+ HICT is capable of increasing the intensity of cardiovascular training compared to the standard FIFA 11+.
Păun et al., 2022	Circuit Football Training Customized for Young Players during and after the COVID Period	Sample size N = 16 players aged 11-12 years.	CT	quasi-experimental	Improvement in performance at both the team and individual levels, there has been an increase in assists (passing), shots and goals (shooting), dribbles (dribbling), interceptions, tackles, and takeovers.
Sunarto et al., 2023	The Effect of Circuit Training on Improving the Physical Condition of Northwest Pantar Football Athletes	N = 60 young players aged 12-16 years.	CT	quasi-experimental	The results of this study prove that circuit training models have a positive impact on the physical condition of football athletes.
Monea et al., 2017	Specific training for improving the skill and speed in junior football players	Data was collected from N = 18 junior soccer players, with an age range of 14-15 years.	CT & IT	quasi-experimental	Players experience a significant improvement in physical condition such as motor skills and speed.
Reza Aprianto Putra et al., 2023	The efforts to improve physical condition throughout the circuit training for U-15	N = 20 junior players U-15.	CT	quasi-experimental	The results of this study show that there was an improvement after the circuit training treatment, with significant results in the physical condition of the players, such as Muscle Endurance, Explosive Power, Speed, and Agility.

players. Whether it is optimal or not can be determined by the appropriate training frequency, such as how often players should attend training in a week. The results of the training will be more apparent when the players achieve the right frequency, so it requires consideration from the coach to develop the physical performance and technical skills of the youth football players.

Excessive training without proper consideration of rest can exceed an individual's adaptation threshold, resulting in negative outcomes such as recurrent fatigue, injuries, and decreased performance. Although frequent and well-structured training can promote physiological and motor development, it must be balanced with adequate recovery to avoid overtraining and injury. The appropriate training frequency for young football players is very important because it is directly related to physiological adaptation, motor development, as well as physical and mental health (Rodrigues et al., 2023).

Based on the explanation above, it can be concluded that the frequency of training is an important factor that must be considered. Training can be optimal if the frequency of training is balanced between the frequency applied and sufficient rest to avoid the risk of injury in young players.

Training Intensity

In circuit training, the intensity of the workout is an important aspect in improving the physical performance and technique of the players. Just like in each station, the number of repetitions performed by the players, certainly varies to enhance both physical performance and technique. Basically, the intensity should be adjusted to the player's condition; if the player is used to low intensity, then it is necessary to increase to moderate intensity and then to high intensity, this is to ensure progress or improvement in the player's performance.

One of the studies by (Reuter et al., 2023) It shows that a gradual increase in training intensity results in a higher VO₂max improvement compared to continuous moderate-intensity training, even though the total energy expended is the same. However, what needs to be noted is the development of players in each training session, whether the intensity can be increased or not to ensure optimal training.

In practice, the intensity of training is usually measured using RPE (Rating of Perceived Exertion). RPE has a valid correlation with training intensity, workload, and physiological responses such as heart rate and lactate levels, making it effective for measuring and controlling endurance training intensity (Lee et al., 2024).

The conclusion drawn is that the intensity of training is an important component in the implementation of CT. The results will be more optimal if the intensity is appropriate and aligns with the players' development and physiology, making it essential to continuously monitor the players' progress during training.

Duration of training

The duration of training in CT is one of the important factors that needs to be planned in the training program to effectively support the improvement of the technical and physical performance of youth soccer players. The duration

of training plays a significant role in determining the intensity, effectiveness in repeating technical exercises, and maximizing physical stimulus. Proper planning of duration in each station and total circuit sessions can help ensure that youth soccer players develop comprehensively without neglecting the safety and motivation of the players.

The right duration of training, well-structured and tailored to the development of young players, can effectively improve performance. Study by (Păun et al., 2022) Circuit training specifically designed for ages 10–12 has proven to consistently assist in achieving physical exercise targets and football techniques, in accordance with the characteristics of the players' age. Another study indicates that CT exercises performed for 60 minutes per session can effectively develop players' technical performance (Farooque et al., 2023). In its implementation, the duration is adjusted to the abilities of young players so that training can optimally develop the performance of young soccer players.

Exercise Variations

Variation in training becomes one of the important components in the application of CT. In this context, variation refers to the use of different types of exercises, whether using different weights, movements, or training models. Variations in CT are not only about creativity but also an important strategy to develop physical performance and technique in a balanced way, prevent boredom, and increase training motivation.

During the training phase of adolescence, it is important to maintain the players' motivation to practice by incorporating variety and fun aspects into the training, which is why CT is well-suited for adolescent players (Păun et al., 2022). Other research mentions that high motivation is related to technical skills, tactics, and self-confidence; this is very important for developing players such as teenagers (Forsman et al., 2016).

The conclusion from the explanation above is that training variation is an important aspect and training variation is also one of the components in CT, where each station must consist of different training models with different objectives and different training loads. CT is a training model recommended for teenage players because it has a variety of exercises that are expected to motivate young players to keep practicing and can optimize the performance of young football players.

The Importance of Physical Performance for Soccer Players

Physical condition is always related to an athlete's ability. Physical condition is one of the most important factors for an athlete to participate in various training programs offered by a coach (Gantois et al., 2020). Good training will have a positive impact on an athlete to achieve expected achievements and goals in a club. Talking about physical condition means talking about physical fitness. This is no longer a foreign matter; an athlete's physical fitness is very important to achieve optimal performance (Menting et al., 2019) Physical condition is one of the important factors needed to improve an athlete's performance (Bernardi et al., 2021). Physical condition is the main factor for an athlete, especially a football athlete, and this factor must be

experienced by a football athlete before learning or training about technique, tactics, and mentality. Therefore, a technique is needed (Sarac et al., 2018). Based on the analysis of 5 selected articles according to the inclusion criteria, there are several aspects of physical performance that improved after circuit training, including speed, agility, muscle strength, cardiovascular endurance, balance, coordination, physical fitness, and motor skills. There are several training models used to improve physical performance, including MICT, HICT, IT, and CT. Below are the procedures and training frequency applied to enhance physical performance.

MICT & HICT Training Model to Improve Physical Performance

The training program is designed based on two groups according to the intensity required. Two experimental groups, namely the HICT group and the MICT group, are involved in high-intensity circuit training (HICT) and moderate-intensity circuit training (MICT), respectively, for sixteen weeks three times a day. The intensity is determined based on the relationship between exercise intensity and HR20. The intensity is set at 75% to 85% of H_{max} for moderate intensity and 85% to 90% of H_{max} for high-intensity training using a heart rate monitor. Meanwhile, the measurement test instruments that can be used are the zigzag running test for agility, the 30-meter speed test for speed, and the standing long jump test for explosive strength. The training method with this procedure is conducted by (Muez Tsegay et al., 2021), the research findings indicate that the HICT group showed a more significant improvement in agility, explosive strength, and speed compared to the MICT group.

In another study, HICT modified with FIFA+ has been proven to improve the physical fitness of young football players (Zein et al., 2020). The FIFA+ program is an initiative from the FIFA Medical Research Centre (F-MARC) that has been proven to reduce the risk of injuries in football players by 30-46% across various age groups, for both men and women (Althomali et al., 2024; Sadigursky et al., 2017; Thorborg et al., 2017). Zein et al. (2020) the modified HICT training procedure with FIFA+ intervention is conducted three times a week and lasts for four weeks. The HICT modification is only applied to part 2 of FIFA 11+, which is the strength and balance training. Six core exercises (plank, side-plank, Nordic hamstring, single-leg stance, squat, and vertical jump) are modified into high-intensity versions. Nordic hamstring is replaced with bridge hamstring, and single-leg stance is replaced with deadlift. Each exercise is performed for 30-40 seconds with a 10-second rest between exercises, after one exercise is completed, the subject should move on to the next exercise until they finish all exercises and then repeat for the next cycle (two sets of circuit training).

Based on the explanation of the training procedure described above, it can be concluded that CT is flexible and can be adjusted to the needs of the coach. However, it is important to note that when creating a training program to improve physical performance, the intensity must be adjusted according to the age of the athlete, especially for teenage players (Arnold et al., 2017). It is recommended for coaches to apply the CT training method by following athlete development guidelines with the LTAD program to

prevent injuries in players (Al Ardha et al., 2024; Zampieri, 2024).

IT & CT Training Model to Improve Physical Performance

Interval training (IT) and CT are training models widely used to develop athletes' fitness, but in their implementation, there are differences in terms of execution structure, types of activities, and training goals. However, in the studies obtained, both training models can be used simultaneously to improve the players' fitness. The research conducted by (Monea et al., 2017) concluding that providing a larger portion of the best methods and ways to develop speed and skills in the physical training of junior soccer players, the improvement in motor skill performance becomes significant. The use of appropriate training methods and tools presented and applied in this research determines the performance of junior soccer players in terms of speed and skills, averaging around 50%.

Technical Skills for Young Football Players

Physical fitness does not directly improve technical skills, but plays a role through the development of fundamental movement skills (FMS) and self-perception of competence. FMS and self-confidence serve as important mediators between physical fitness and technical skills in young players (Duncan et al., 2022). At the golden age, technical skills are fundamental that young football players must master, as technique is a basic element in football matches. The youth phase (around 8-14 years old) is the most effective time to develop basic techniques such as passing, dribbling, shooting, and ball control, as the adaptability response is very optimal at this age (Jia et al., 2021). The better the motivation for training, physical fitness, and motor skills of the athletes, the better their level of ability in mastering the basic techniques of football (Nurcahyo et al., 2025).

CT is one of the interesting training models that can enhance the motivation, physical fitness, and motor skills of athlete (Aaron Francis Niles, 2023; Sakthivel & Rangaraj, 2025). In the selection process that has been carried out, 1 article was obtained that meets the inclusion criteria for improving technical skills. The research results show that CT can enhance skills in passing, shooting, dribbling, interceptions, tackles, and takeovers (Păun et al., 2022). Here is the model along with the training frequency applied to improve basic techniques.

CT to Improve Basic Techniques

The analysis results found that CT also serves to enhance the technical aspects of young players. Simultaneously, the technical-tactical aspects can significantly improve by using the CT method (Păun et al., 2022). This finding proves that CT can be used not only for physical performance but can also be applied to improve the technical skills of football players.

CT is a Training model that consists of several stations, allowing the coach to vary each station according to the coach's objectives. In study (Păun et al., 2022) applying post-pandemic CT for 11-12 years old athletes, where each station consists of six exercises and focuses on the technical-tactical

aspects of the player. Training is conducted in the middle of a competition for 4 months consisting of two phases (autumn and spring), training is held every Tuesday and Thursday for 20-50 minutes. Training goals in the early season phase: Focus on basic technical training such as passing, dribbling, shooting, and ball control. End of season phase: Application of circuit methods to improve speed, creativity, teamwork, and spatial orientation on the field. By using the CT statistic training method, the team experienced significant improvements in the number of tackles, dribbles, assists, and goals. The decrease in fouls indicates an improvement in sportsmanship and better defensive techniques. There was an increase in shooting efficiency (fewer shots, but more goals scored).

Conclusions

Based on the literature analysis that has been conducted, a total of 6 articles passed through the PRISMA selection process. From these 6 articles, it can be confirmed that CT can be used to improve the physical condition of players such as physical fitness in preventing injuries, speed, agility, muscle endurance, explosive power, and player techniques such as passing, shooting, dribbling, interceptions, tackles, and take-overs. In the application of CT, it is important to pay attention to the frequency of training, duration of training, intensity of training, and variation of training so that CT can be used effectively for players. In addition, from the articles obtained, there is only 1 that researched the effectiveness of CT on the techniques of youth soccer players. In improving physical aspects, there are training models used, namely HICT, MICT, IT, and CT, while for improving technique, the CT training model is used. The author sees opportunities for future researchers to conduct CT research that enhances the technical aspects of young football players. From the literature results, it can be concluded that CT is a flexible training method and very useful for coaches to apply to young football players.

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Conflict of Interest

The authors reported no conflicts of interest.

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Вплив методу колового тренування на поліпшення технічних навичок та фізичної працездатності юних футболістів: Систематичний огляд

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 1 табл., 1 рис., 54 джерел.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу методу колового тренування (КТ) на поліпшення технічних навичок та фізичної працездатності підлітків-футболістів, а також у забезпеченні розуміння щодо ефективного застосування КТ.

Матеріали та методи. У представленому дослідженні процес відбору проведено із використанням фільтра рекомендацій із пріоритетних елементів звітування для систематичних оглядів та метааналізів (PRISMA). Для пошуку наукових джерел, що охоплюють метод колового тренування в контексті покращення технічних показників та фізичної працездатності або підготовленості, використовувалися чотири наукометричних бази даних, до яких належать ScienceDirect, Scopus, Google Scholar та PubMed, що містять публікації за період з 2015 по 2025 роки.

Результати. За результатами огляду літератури, проведеного в рамках цього дослідження, після ретельного відбору з 878 статей було визначено 6 статей, прийнятих для подальшого аналізу. Серед отриманих 6 статей: 5 — зосереджувалися на покращенні фізичної працездатності, а 1 стаття була присвячена вдосконаленню технічних навичок. У процесі імплементації необхідно звертати увагу на частоту, інтенсивність, тривалість та різноманітність тренувань. Результати представленого огляду свідчать, що методика КТ довела свою ефективність у поліпшенні технічних навичок та фізичної працездатності юних футболістів.

Висновки. На основі результатів аналізу встановлено, що КТ сприяє поліпшенню фізичного стану підлітків-футболістів, зокрема фізичної підготовленості у запобіганні травматизму, швидкості, спритності, м'язової витривалості, вибухової сили, а також технічних навичок гравців, як-от виконання пасів, ударів, дриблінгу, інтерцепції, відбирання та перехоплення м'яча. З метою покращення фізичних аспектів можна використовувати такі моделі тренувань, як високоінтенсивне колове тренування (ВІКТ), колове тренування помірної інтенсивності (ПІКТ), інтенсивне тренування (ІТ) та безперервне тренування (БТ), тоді як для вдосконалення техніки можна застосовувати модель КТ. Очікується, що результати цього дослідження відкриють можливості для інших науковців щодо застосування зазначеної моделі з метою розвитку технічних навичок.

Ключові слова: колове тренування, технічні навички, фізична працездатність, огляд літератури, юні футболісти.

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Ascertaining the Evolution and Research Trends on Virtual Reality in Archery: A Bibliometric Analysis

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Abstract

Background. The development of VR archery technology provides easiness of the faced difficulties by giving real visualization and new experience for the users.

Objectives. The present study aimed to ascertain trends, evolution, research spread and research approach related to VR archery.

Materials and methods. A literature analysis was conducted using bibliometric analysis approach. Harzing's publish or perish, Mendeley desktop, and Vos viewer were applied in this present study. A total of 77 articles from 2015 to 2025 were identified in the Scopus database using the keywords "VR archery", "Archery Virtual Reality", and "Virtual Reality Archery". According to study, 42 articles were found to be duplicated, 3 articles were incomplete, and 2 articles were excluded on the basis that they were not relevant to the subject. The Vos viewer was employed to analyse a total of 30 articles. In the process of sample description, it was examined the number of annual published articles, yearly citation, and articles with the most citation. A bibliometric analysis revealed research evolution each year, influencing publication and research trend related to Virtual Archery.

Results. The results of co-author analysis, bibliographic coupling, keyword co-occurrence, and overlay visualization revealed collaboration among researchers, the relation among articles, and network spread forming a cluster. Furthermore, the obtained data provided detailed knowledge concerning the 11-year period of VR archery development, focusing on the formed cluster, significant publications, and collaboration network.

Conclusions. The findings of this study were beneficial for researchers in developing VR archery in the future and for research practitioners in facilitating to solve difficulties through VR technology.

Keywords: virtual reality, archery, archery education, sport performance, bibliometric analysis.

Introduction

The development of technology provided so many easiness for human to perform both their work and daily activity. Purchasing of thing or food could be done without face to face meeting through e-commerce. Interdisciplinary sharing of experts could be performed through network using virtual meeting application. The advanced development of technology also gave benefit in sport and education achievement (Huang & Yongquan, 2025). The use of technology in educational sports aimed at increasing student

interest in the learning process in order to meet learning achievements (Roth et al., 2025). Meanwhile, in sports field, technology development was widely used in developing digital learning tools, digital analysis and evaluation, independent training applications, digital scores. The use of technology in competitive sports was used to develop components affecting sports performance and prevent injuries (Xu & Baghaei, 2025). The components influencing sports performance included bio motor, technical, tactical, and mental components (Bompa & Carrera, 2015).

The development of Virtual Reality (VR) technology had been widely discussed lately. VR was a technology allowing someone in an illustrated or simulated environment by creating a real/immersive experience (Ishida & Shimizu, 2023; Linne et al., 2024). This innovation was existing by the emergence of VR technology in several games (Sun &

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Chai, 2025). VR technology was developed by several sports aiming at creating digital product which support the more accurate and efficient evaluation and training (Dal et al., 2024; Westmattmann et al., 2025). VR technology was also developed in the process of rehabilitation, increased fitness, and increased life quality in the community (Lattré et al., 2025; Wang & Wang, 2025). Besides, VR technology was created to promote sport, education, independent evaluation, and to improve sport performance (Cao et al., 2025; Pastel et al., 2025; Zhu, 2025). The emergence of VR technology actually provided benefits in form of real experience and motivation for its users (Godoy Cumillaf et al., 2025).

The development of VR in archery was carried out to overcome various difficulties by providing an immersive environment. Archery was one of the competitive sports competed in the Olympics. Before archery was included in a competitive sport, it was one of the cultural heritages in several countries from ancestors to be preserved. The previous studies showed that VR technology in archery could be used to improve athletes' skills and understanding (Richlan et al., 2023). The developed VR technology might also help youth to understand traditional archery as cultural heritage (Butnariu et al., 2018; Ishida & Shimizu, 2023). The present study analysed how far the VR archery development by analysing the dependent variables. The analysis was referred to the references having high influences and reliability, which was expected to reveal the developed VR archery. The description allowed the possible research gap, which could be studied further. In addition, the findings in the present study could be used as underlying theory in developing VR archery technology in the future.

Materials and Methods

The present study was literature study to know trends, evolution, research spread and research approach related to VR archery using bibliometric analysis. Bibliometric analysis was a literature study analysis used to find mapping, research gap, and research chances (Guntoro et al., 2024; Prasetyo et al., 2024). The analysis of the articles published in recent ten years taken from reliable data base allowed to result in underlying theory in the future research.

Data Source

Data base Scopus used in the present study. Articles included in the scopus database were believed to have high influences and got several reviews from the trusted reviewer team. The finding, therefore, from the database provided specific and deep information.

Data Selected and Analysis

To select articles, the writer used three applications, which were harzing publish or perish, Mendeley desktop, dan Vos viewer. Harzing publish or perish was used to sort articles based on the keywords, data base, article types, and publication year. Mendeley desktop was used for completing data and for eliminating irrelevant topics. In addition, Vos viewer was used for mapping research trends relating to the selected topics. The mapping was presented based on the writers, keywords and journals.

Procedure

The writer searched articles on the Scopus data base using harzing publish or perish application. The keywords used in searching were "VR archery", "Virtual Reality Archery", and Archery Virtual Reality". The time period in the system setting was research report published from 2015 to 2025. It was found 77 publications, in which the detail of "VR archery" was 22 publications, "Virtual Reality Archery" was 32 publications, and "Archery Virtual Reality" was 25 publications. The whole publications were then sorted using Mendeley desktop application. The basic of article sort were the suitability of the research topic, articles written in English, articles had complete component, and no duplication. The suitability of the research topic was when the article analysed VR in archery sport. After analysis, there found 47 articles eliminated due to similar or duplication of 42 articles, 3 publications with incomplete information, and 2 irrelevant articles. There were 30 articles eligible to analyse further.

30 eligible articles were then analysed using Vos viewer. Results of the analysis showed (1) Sample descriptions

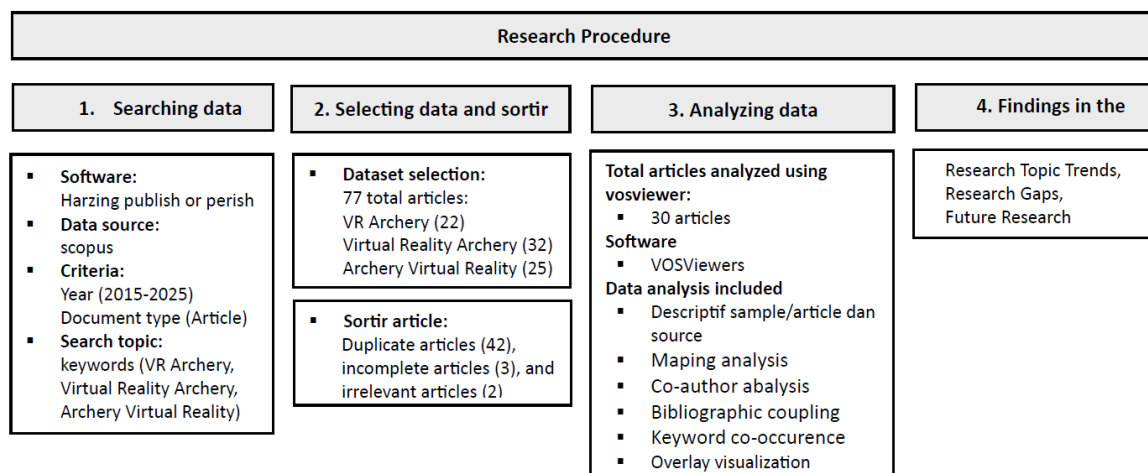


Fig. 1. Research procedure

containing publication number and citations each year and articles with the most citations. (2) Mapping analysis including co-author analysis, (3) Bibliographic coupling containing publisher ranking, keyword co-occurrence, clusters, and overlay visualization.

Results

The results of the bibliometric analysis describe the evolution of research each year, influential publications, and research trends related to Virtual Archer. In addition, the results of the study also describe the analysis of co-authors, bibliographic coupling, keyword co-occurrence, and overlay visualization describing collaboration between researchers, relationships between articles, and the distribution of networks that form clusters. A detailed description can be seen in the following sub-chapter.

Sample Description

Initial description of the publication sample with VR archery topics revealed collected publication development in one period. Figure 2 presents first period started from 2015 to 2020 and the second period started from 2021 to 2025. Research in first period in 2015 was started by the emergence of virtual technology development for rehabilitation process of stroke patients (Seo et al., 2016). The technology arranged to give patients easiness in rehabilitation process at home. VR games in former development was cooking game, archery, puzzle designed to improve patients' motivation for movement accessibility. Through time, the VR archery development was in form of games, training media for accurate training, to sensor use in VR archery (Adachi et al., 2020; Butnariu S et al., 2018; Park et al., 2017; Yasumoto & Teraoka, 2019).

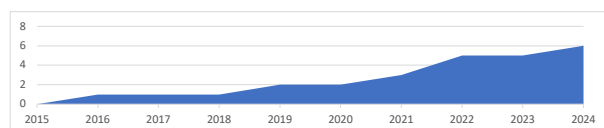


Fig. 2. Number publication per year

On the second period, it started from 2021 to 2025. Research in 2021 started to analyse VR technology developed to improve head and body coordination for children through virtual archery game (Esposito et al., 2021). In the further research, it needs to develop human interaction and drone-augment reality allowing them to browse virtually. The development can be fundamental aspect in developing tools for search and rescue of victims, monitoring plants, and inspection (Dorzheva et al., 2022). For further research, VR archery development mostly focus on media development for training and its evaluation in improving the achievement (Dal et al., 2024; Richlan et al., 2023). However, VR archery development in the scope of introducing archery for community to improve interest and as education means is still performed (Nakamura & Ushida, 2024).

Figure 3 shows the citation number of articles each year. The peak of the citation was on the first period in 2016. The citation taken from the articles in 2016 was caused by little publication in this year. The researchers, therefore, cited that year articles as underlying theory in their researches. In the second period, the citation rate was increased as well as

decreased. The decrease in citation number in the second period occurred in 2024. It was common in newly published research. While the high number of citations in the second period occurred because the documents in each year was quite large, so the resulting citations also tended to be higher. The citation number, however, obtained in the first period was still superior than citation number in the second period.

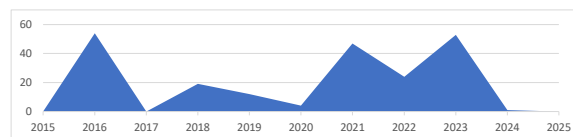


Fig. 3. Citation per year

Table 1 reveals the most cited articles of 30 articles analysed. Many citations were divided into two periods, in which the first period consisted of three articles belonging to most cited articles. It was due to the first period articles have been published in long time, causing more citation recorded. The article number on the first period was also less than the second period, causing writer had no more articles as references. The first period articles analysed the use of VR archery technology in rehabilitation, immersive VR simulator to give aiming opportunity, and VR to complete independent training by providing guidance and feedback (Butnariu S et al., 2018; Seo et al., 2016; Yeo et al., 2019). The most cited articles in second period consisted of two articles. Those articles analysed the impact of VR on sport performance, for example virtual reality-based imagery (VRBI) toward the aiming ability and imagery athlete (Bedir & Erhan, 2021; Richlan et al., 2023).

Table 1. Most cited publications

Publication Title	Authors	Year	Citations
Usability evaluation of low-cost virtual reality hand and arm rehabilitation games	Seo et al.	2016	54
Virtual training, real effects: a narrative review on sports performance enhancement through interventions in virtual reality	Richlan et al.	2023	44
The Effect of Virtual Reality Technology on the Imagery Skills and Performance of Target-Based Sports Athletes	Bedir & Erhan	2021	41
An interactive haptic system for experiencing traditional archery	Butnariu S et al.	2018	19
Augmented learning for sports using wearable head-worn and wrist-worn devices	Yeo et al.	2019	11

Mapping analysis

Co-author analysis

Table 2 revealed the common citation number by most cited author. Result of analysis revealed ten categories of

author with highest link strength, in which the ten authors had same link strength, which was 6. The number of highest citations was Baza, Ahmed et.al who were an author group in an article having highest link strength, which was 10. It was continued by Kim, Taejun with document number of 2 and 10 citations and Ferrández-Vicente, José Manuel et.al with total citation of 2.

Table 2. Co-author analysis

Author	Publication year	Total link strength	Citations
Baza, Ahmed	1	6	10
Cabrera, Miguel Altamirano	1	6	10
Dorzhieva, Ekaterina	1	6	10
Fedoseev, Aleksey	1	6	10
Gupta, Ayush	1	6	10
Karmanova, Ekaterina	1	6	10
Kim, Taejun	2	6	8
Ferrández-Vicente, José Manuel	1	6	2
Gómez-Rodellar, Andrés	1	6	2
Gómez-Vilda, Pedro	1	6	2

Bibliographic coupling

Bibliographic coupling was used to look at the relation of document based on reference list. The bibliographic coupling analysis aimed at seeing the similar topic of the documents, to result in mapping. The mapping was useful for finding research gap for further research.

Table 3 illustrates the rank of 5 journals or conferences arranged based on the published articles and gotten citation concerning to the topic analysed which is “VR Archery”. The table illustrates publication sites with widest spread. The most published journal was “Frontiers in Psychology” with two publications or documents and 85 citations. It is continued by “Journal of Rehabilitation Research and Development” with 1 publication/document and 54 citations. “Acta Polytechnica Hungarica” with 1 publication/document and 19 citations. “26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019 – Proceedings” with 1 publication/document and 11 citations. Lastly, “Proceedings - 2022 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2022” with 1 publication/document and 10 citations.

Concerning to research related to “VR archery” was little analysed, the use of VR archery began to develop on the field of education, rehabilitation, psychology training, technical training and training to support sport achievement. Journal of “Frontiers in Psychology” became references mostly cited and had two documents. The document discussed about the efficacy of Virtual Reality Based Imagery (VRBI) to improve aiming ability and imagery skills of athletes (Bedir & Erhan, 2021). The second document analysed the previous study through literature study concerning VR in improving sport performance. Finding of the previous study showed that VR intervention had potentially real effect to improve sport performance through skill and psychological training including skills of actions, strategy, tactic, and decision

Table 3. Documents and citations per source

Source	Document	Citations
Frontiers in Psychology	2	85
Journal of Rehabilitation Research and Development	1	54
Acta Polytechnica Hungarica	1	19
Proceedings - 2022 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2022	1	10
26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019 – Proceedings	1	11

making to respond to unpredictable events (Richlan et al., 2023). “Journal of Rehabilitation Research and Development” developed VR in form of archery game used for stroke patient rehabilitation program (Seo et al., 2016).

“Acta Polytechnica Hungarica” published a document analysing the use of VR to improve human cognitive to understand mechanism of how ancient ow worked in archery sport (Butnariu S et al., 2018). ‘Proceedings - 2022 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2022’ published a document analysing drone-archery development through augmented reality (AR) human-drone to improve aiming skill (Dorzhieva et al., 2022). “26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019 – Proceedings” published a document developing tools to help people performing independent training and was completed with feedback given on several sports including archery (Yeo et al., 2019).

Keywords co-occurrence

Keywords co-occurrence was analysis used to know the keywords resulting in trend/pattern of research topics being analysed. This analysis also revealed relating topics studied through times. Figure 3 illustrates the co-occurrence of keywords which were often used by authors. The colour difference of each bullet illustrates the keyword groups that perhaps were cited together. The bullet size illustrates the keywords frequently used. The big bullet size illustrates the frequently used of the keywords, while the small size bullet illustrates the rarely used keywords. The narrow space between one bullet to another illustrates the keywords relationship. The narrow space between bullet described the high interest and allowed to take together, while the far space one described the low interest.

Figure 4 shows clearly the keyword of “virtual reality” accompanied by other keywords of “archery” and “archery game”. Further exploration illustrates the cluster groups based on colour, in which the analysis result showed four cluster, which were brown, red, green and blue clusters.

Cluster I (brown) is called as “the development of virtual reality technology” consists of virtual reality, attentional control, eye tracking, mindfulness meditation, shooting, physical education, and archery game. The cluster presents publication about the development of the use of virtual reality technology in education, in preservation of

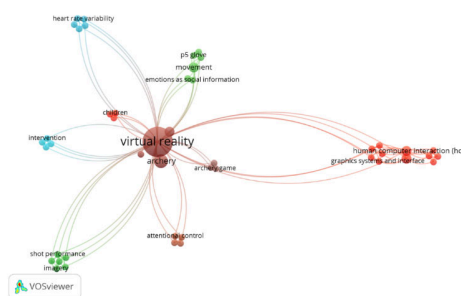


Fig. 4. keywords co-occurrence

traditional archery and in improving sport performance. Besides, the cluster also provided publication of collaboration use of sensor and virtual reality technology in improving performances in sport achievement.

Cluster II (red) is then called as “virtual reality assessment and Augmented reality (AR)” consists of computer interaction, mixed/augmented reality, head-trunk coordination, and children. The cluster presented publication about how virtual reality technology was developed to assess the coordination of head and body on children. Besides, this cluster provided Augmented reality (AR) human-drone developed to improve aiming and as base in developing tools for searching and rescuing as well as monitoring of farming in further research.

Cluster III (green) is then called “rehabilitation” consists of imagery, shoot performance, target spot, rehabilitation, stroke, and emotion as social information. The cluster showed independent training program by using virtual reality technology planned particularly for patients having stroke.

Cluster IV (blue) is then called as “virtual reality effect on psychology and psychophysiology” consisting of psychophysiology, vagal tone, virtual reality archery, intervention, performance, health rate variability. This cluster presented the difference of psychophysiological responses in the use of real archery and VR archery. The cluster also analysed virtual reality archery, which was beneficial on athletes’ psychology in form of perception-action skill, strategy, tactic, decision making, unpredictable occurrence response, and in improving psychological defence under pressure.

Table 4. Co-occurrence of author keywords

No	Keyword	Occurrences	Total link strength	Citation
1	Virtual reality	18	71	168
2	Movement	2	13	56
3	Game	2	12	54
4	Human Computer Interaction (HCI)	2	12	11
5	Human-centered Computing	2	12	11
6	Archery	4	10	6
7	Finger	1	9	54
8	Hand	1	9	54
9	Kinect	1	9	54
10	Motion	1	9	54

Table 4 shows the keyword emergence frequency list, link strength, and total document. As illustrated in Figure 3, the keyword of “virtual reality” is the most frequent used keyword with frequency link strength of 18 and 71, subsequently. Then, it is followed by other keywords related to main keyword.

Figure 5 illustrates the development of research topic through time. The difference of colour each bullet shows topic analysis period. The dark colour shows research topic in the past, while the light colour shows newest research topic. VR archery game was past research topic focusing on rehabilitation program to train movement on patients with stroke. Through time, VR archery was developed to train motoric for children. The newest research on VR archery was the development of sport performance through tracking heart rate (physiology) to imagery training (psychology).

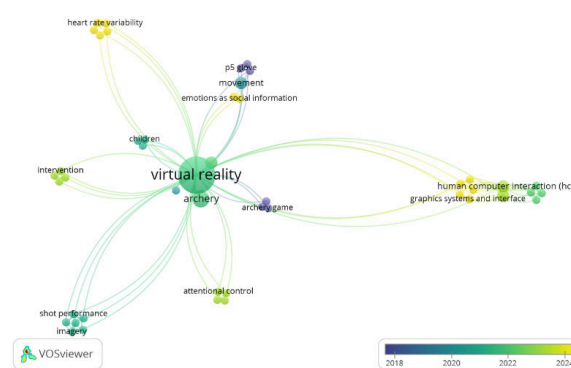


Fig. 5. Overlay visualization

Discussion

VR Archery was 3D game using Virtual Reality (VR) (Riwinoto & Harviando, 2023). The technology was displayed in real form to give real experience for users (Y. Shim et al., 2022; Y. A. Shim et al., 2022; Yasumoto & Teraoka, 2019). A mask or blindfold were used to show a live preview of the virtual environment which allows the user to feel in a real environment (Linne et al., 2024). Shooting-Based Technique (SBT) was a highly interactive VR archery movement method in virtual reality (VR) that allows the user to navigate through a simulated target-aiming action (Li & Takashio, 2023). The results of analysis illustrated that VR technology was used in preserving cultural heritage by depicting the operational visualization of traditional archery to improve students’ understanding (Butnariu S et al., 2018; Dong & Yu, 2020). Kyudojo VR (training hall) and VR bows and arrows were developed identically to those used in real Kyudojo allowing users to have an immersive and realistic Kyudo experience (Ishida & Shimizu, 2023).

Besides, with the advanced continuous development of technology, the virtual reality (VR) technology was introduced in the field of physical education and it has been updated tools in innovative learning method (Jiang et al., 2024). The use of VR technology in teaching played an important role in increasing students’ motivation in learning (Zhang, 2021). For example, the use of virtual reality as a means to monitor students’ psychomotor skills (Palacios-

Alonso et al., 2022; Purnomo et al., 2022). VR development was used for independent learning and was equipped with feedback (Yeo et al., 2019). Feedback was an important component of the learning process that focuses on the results achieved (Krasovsky et al., 2024).

Result of analysis also revealed that VR archery could be used to improve sport performance. Intervention in VR had potential to cause real effect in improving sport performance through skill training and psychological aspect of athlete (Richlan et al., 2023). For example, the training of mindfulness during pre-competition period could improve focus (Gao & Zhang, 2023). VR as archery training tool helped in managing anxiety, difficulties, self-confidence, energy exposure speed felt (RPE), and shooting performance (Dal et al., 2024). Besides, the development of VR with AI is expected to assist the training evaluation process. The sport not only uses big data traditionally got but also virtual and added reality (Shin et al., 2024).

In wider use, the VR archery game was developed in a rehabilitation program for patients with stroke and in future research it is expected that it can be developed for patients with neurodegenerative disorders (Palacios-Alonso et al., 2022; Seo et al., 2016). VR archery was started to develop specially for blind people with the use of audio to give more experience for more users (Mendes et al., 2025). Then, to get more benefit in the future, the collaboration of VR and AR technology is expected to be applied in various parts, for instances in searching and rescuing, plant monitoring, inspection, and maintenance (Dorzhieva et al., 2022).

Implication and Further Research

The analysis of virtual reality in archery is little done during the decade. However, the bibliometric analysis been conducted provides several insights concerning to virtual reality development done by previous researchers. The finding of the present study, therefore, contributes in expanding knowledge of virtual reality in archery sport. Results of the initial description have outlined several topics that can be used as a basis for developing VR archery by considering several things. For example, topic relating to VR archery having potential to develop in the future, the reference availability, weakness and shortcomings of traditional methods with the use of VR in archery.

It entirely gives benefit for researcher to understand the variables relating to virtual reality and the theory. For example, to find underlying theory allowing VR archery in assisting rehabilitation process and psychomotor (Purnomo et al., 2022; Seo et al., 2016). Finding the underlying theory about the benefit of VR archery in developing psychology and physiology skill of athletes (Richlan et al., 2023). Finding and investigating the collaboration of several technologies like Virtual Reality (VR), Augmented Reality (AR) and sensor in improving performances in sport achievement (Adachi et al., 2020; Dorzhieva et al., 2022). It is also beneficial for practitioner. The research finding may enlarge the coach view point concerning the development of technology contributing the training process.

The findings in this study gives opportunities or gaps from previous research findings and become the basis for determining research topics related to VR archery in the future. First, the development of VR archery for independent

rehabilitation processes in improving functional movement due to limited movement, stroke, sports injuries and neurodegenerative (Palacios-Alonso et al., 2022). The development of injury therapy and rehabilitation in the form of VR can increase motivation and provide new experiences for patients in the healing process. Second, the development of VR archery to train the movement coordination for beginner archery athlete. Third, the development of VR archery game, which can be used as promotion to improve community's interest toward archery sport. Fourth, the development of VR technology includes analysis of biomechanics, energy system, physiology, and psychology to improve archery athletes' performances. Fifth, the development of VR archery competition.

Conclusions

The research finding provides detailed knowledge concerning the period of VR archery development during 11-year period, the cluster formed as main field focus, big contribution publication, and collaboration network. Virtual Reality developed in archery sport in 11 years was VR archery for rehabilitation process, VR archery for coordination improvement, VR archery for learning, VR archery for improving sport performance, collaboration of VR, AR, and sensor technologies in sport achievement. VR technology which have been developed gave benefit for users and practitioner to fulfil their needs. The finding of the present study can be used by researcher as underlying theory in developing VR. The number of research relating to VR archery was still limited, so it has gap for further research.

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Conflict of Interest

The author has no conflict of interest.

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Визначення еволюції та дослідницьких тенденцій щодо застосування технології віртуальної реальності у стрільбі з лука: Бібліометричний аналіз

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 4 табл., 5 рис., 39 джерел.

Історія питання. Розвиток технологій віртуальної реальності у стрільбі з лука полегшує вирішення існуючих труднощів, надаючи користувачам реальну візуалізацію та новий досвід.

Мета дослідження. Мета цього дослідження полягала у визначенні тенденцій, еволюції, поширення досліджень та дослідницького підходу, пов'язаних зі стрільбою з лука у віртуальній реальності.

Матеріали та методи. Проведено аналіз літератури з використанням бібліометричного аналітичного підходу. У представленому дослідженні було застосовано програмне забезпечення Harzing's Publish or Perish, Mendeley desktop та Vos viewer. У наукометричній базі даних Scopus за допомогою ключових слів "VR archery", "Archery Virtual Reality" та "Virtual Reality Archery" встановлено загалом 77 статей за період з 2015 по 2025 рік. Згідно з дослідженням, виявлено 42 дубльовані статті, 3 статті були неповними, а 2 статті було виключено на підставі відсутності їхньої релевантності до предмета дослідження. За допомогою програмного забезпечення Vos viewer було проаналізовано загалом 30 статей. У процесі опису вибірки було досліджено кількість щорічно опублікованих статей, щорічну кількість цитувань та статті з максимальною кількістю цитувань. Бібліометричний аналіз виявив щорічну еволюцію досліджень, що впливає на публікації та тенденції досліджень, що стосуються галузі віртуальної стрільби з лука.

Результати. Результати застосування співавторського аналізу, методу бібліографічного сполучення, частоти спільної зустрічності ключових слів та візуалізації накладення дозволили виявити співпрацю між дослідниками, взаємозв'язки між статтями та поширення мережі, що утворює кластер. Крім того, отримані дані надали детальну інформацію щодо 11-річного періоду розвитку віртуальної реальності зі стрільби з лука, акцентуючи увагу на сформованому кластері, значущих публікаціях та мережі співпраці.

Висновки. Результати дослідження виявилися корисними для дослідників у подальшому розвитку віртуальної реальності зі стрільби з лука, а також для науковців-практиків у сприянні розв'язанню труднощів завдяки впровадженню технології віртуальної реальності.

Ключові слова: віртуальна реальність, стрільба з лука, навчання стрільбі з лука, спортивна результативність, бібліометричний аналіз.

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Review Article

Beyond the Whistle: Mapping Global Trends in Physical Education Teaching Methods through Bibliometric Analysis

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Abstract

Objectives. Focusing on the increasing importance of new pedagogies that incorporate technology, inclusivity, and student-centered approaches, this bibliometric study examines the development and current trends in physical education (PE) teaching methods from 2020 to 2024. In order to guide future research and practice, the study aimed to map the field's intellectual structure, identify significant contributors, and highlight emergent topics.

Materials and methods. The study employed bibliometric techniques, including co-citation and co-word analysis, to rigorously assess publishing patterns, influential works, and theme clusters using data from 278 articles that were retrieved from the Web of Science.

Results. The results show a notable rise in scholarly output, which peaked in 2022 and was mostly contributed to by China and Spain. Key players include universities like the University of Extremadura and core writers like Feu and Ibanez. Dominant foci, such as curricular innovation, technological integration (e.g. gamification and the Internet of Things), and motivational techniques, are highlighted by thematic clusters. The interaction of pedagogy and technology is emphasized by high-impact research, comprising those conducted by Demchenko et al. on inclusive teaching and by Ding et al. on digital tools. Sub-themes such as teacher roles in health promotion and game-based learning are further defined by co-word analysis.

Conclusions. The findings of this study underscore a move towards multidisciplinary and hybrid approaches, which is consistent with worldwide trends in education. However, issues like resource inequalities and teacher readiness still exist. In order to close the gaps between theory and practice, the study concluded with recommending focused professional development, fair resource distribution, and additional research. This study acts as a fundamental resource to promote collaborative innovation in the field and advance evidence-based physical education pedagogies.

Keywords: physical education, teaching methods, bibliometric analysis, hybrid models, educational technology.

Introduction

The importance of physical education (PE) in supporting students' social, cognitive, and physical development has drawn a lot of attention to research on teaching strategies. Though modern approaches promote holistic education by combining personal responsibility, teamwork, and strategic thinking, traditional pedagogies have frequently placed an emphasis on skill acquisition and physical health. Studies like those by Mesquita et al. (2012) and García-Ceberino et al. (2020) demonstrate how well hybrid methods like Sport Education and Teaching Games for Understanding (TGfU) work to increase students' tactical awareness and

involvement. In a similar vein, Ding et al. (2020) show how incorporating technology, such as the Internet of Things (IoT), can produce inclusive and flexible physical education settings that serve a variety of learners.

The development of PE teaching strategies is in line with more general trends in education, such as blended learning, flipped classrooms, and gamification. By tackling global issues like teenage physical inactivity, these innovations seek to improve motivation and inclusivity (Braithwaite et al., 2011; Segura-Robles et al., 2020). Furthermore, hybrid models are emphasized by García-Castejón et al. (2021) as a means of fostering social responsibility and teamwork. Researchers can find trends, gaps, and future directions by using bibliometric analysis to examine various methodologies, ensuring that physical education teaching practices continue to progress.

Innovative teaching strategies are becoming more and more important in physical education (PE), but there are still obstacles to overcome in order to successfully incorporate these strategies into a variety of educational contexts. A lot of conventional approaches don't work for kids with different skill levels or needs. The challenges of implementing inclusive solutions in physical education, especially when it comes to meeting the requirements of students with disabilities, are highlighted by research by Demchenko et al. (2021). Similarly, Zheng et al. (2021) show inconsistent student performance throughout the COVID-19 pandemic, highlighting flaws in blended learning strategies. The insufficient knowledge of how virtual teaching technologies affect long-term skill development and motivation is another point of emphasis for González-Calvo et al. (2022). Finding efficient, scalable, and flexible teaching strategies that improve PE learning outcomes and experiences requires more research into these problems.

In physical education (PE), creative teaching strategies are essential for fostering students' mental, emotional, and physical growth. According to Goodyear and Dudley (2015), student-centered methods have a transformative effect that promotes independence and lifetime physical exercise. Furthermore, Pozo et al. (2018) emphasize how frameworks for societal and personal responsibility can foster moral principles and teamwork. According to research by Bailey et al. (2009), contemporary pedagogies improve overall educational outcomes and support students' holistic development. These strategies are crucial for educational transformation and public health enhancement as physical education increasingly tackles global issues like physical inactivity.

There are many obstacles to overcome when implementing novel PE teaching strategies, such as teacher preparedness, resource constraints, and technology integration. According to García-Espinosa et al. (2020), ineffective teacher preparation frequently prevents modern pedagogies from being delivered effectively. Technology inequalities limit access to resources like flipped classrooms and gamified classes, according to Hinojo Lucena et al. (2020). Additionally, structural problems including insufficient policies to encourage physical activity instruction are highlighted by Guthold et al. (2020). Targeted approaches are needed to address these issues, including increased institutional support for creative teaching methods, fair resource distribution, and professional development.

Materials and Methods

A vital tool for methodically analyzing the evolution and significance of research in physical education (PE) teaching methodologies is bibliometric analysis. It allows academics to track theme evolutions, identify key articles, and evaluate worldwide trends. Zhou et al. (2023) highlighted the increasing use of digital tools in traditional teaching and stressed how bibliometric analysis can highlight the connections between online education and physical education. Similar to this, Marín-Suelves et al. (2023) investigated how technology affected physical education during the pandemic, highlighting the usefulness of bibliometric techniques in mapping flexible teaching approaches. The importance of bibliometric research in

evaluating the efficacy of hybrid teaching models—which blend conventional and cutting-edge pedagogies—was further emphasized by Alcóser et al. (2023).

Bibliometric analysis lays the groundwork for improving instructional strategies by spotting trends and gaps. By examining global trends in PE teacher education and revealing the changing pedagogical techniques in various countries, Yanar and Avşar (2023) illustrated its potential. Using bibliometric approaches, Perdima et al. (2022) investigated how educational technology was used in physical education, illuminating its transformative potential to improve learning outcomes. In their study on Teaching Games for Understanding (TGfU), Ortiz Gómez et al. (2023) employed bibliometric analysis to evaluate the model's popularity and efficacy during the previous five years. Together, these research show how bibliometric techniques help improve physical education instruction.

Furthermore, bibliometric analysis promotes a better comprehension of the field's major contributors and intellectual framework. In their investigation of the integration of digital technology into physical education pedagogy, Sargent and Casey (2021) highlighted significant publications and exposed networks of researchers that collaborate. This was furthered by Baytur and Ulaş (2022), who examined studies on sports education models and showed how they influence curriculum and policy. According to Zhou et al. (2023), bibliometric techniques allow for the discovery of new trends in physical education teaching methodologies by measuring research production as well as offering insights into cross-disciplinary impacts.

Finally, by offering data-driven insights into successful teaching strategies, bibliometric analysis aids in evidence-based decision-making. Marín-Suelves et al. (2023) demonstrated how bibliometric techniques might assess the effects of pandemic-driven changes toward technology-enhanced physical education instruction. Alcóser et al. (2023), who argued for the wider use of hybrid models in response to changing educational demands, concur with these observations. Bibliometric analysis is crucial in influencing the direction of physical education teaching approaches in the future and guaranteeing their conformity with international educational objectives by showcasing influential research and developing fields.

Inclusion Criteria

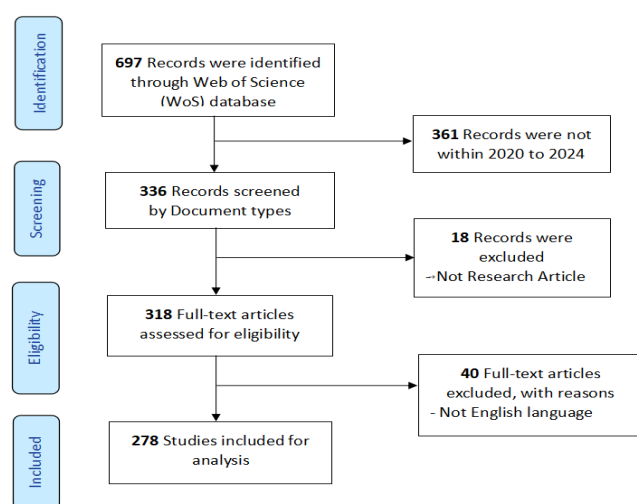
Precision and relevance are given top priority in the inclusion criteria for this bibliometric analysis of physical education teaching methods, guaranteeing that the dataset includes the most relevant research in the area. A preliminary search of the Web of Science database with the keywords “physical educat*” or “PE” and “teach* method*” yielded 697 articles. By using particular filters, such as publishing years (2020–2024), English-language texts, and document categories limited to articles and review articles, this dataset was narrowed down to 278 (Table 1). The criteria guarantee that chosen studies directly address the intersection of physical education and teaching methodologies by concentrating on the title search field (TS), thereby removing irrelevant works. This procedure demonstrates the increased scholarly interest in creative physical education teaching methods, especially in the last four years.

Table 1. Inclusion Criteria for Bibliometric Analysis

WoS Database	ALL
Time period	2020 to 2024
Search field	TS
Search keywords	“physical educat*” OR “PE” AND “teach* method*”
Citation Topics Meso	ALL
Document type	Article or Review Article
Language	English

Findings

The citation and publication activity pertaining to physical education teaching techniques from 2020 to 2024 is graphically represented by the PRISMA flowchart (Figure 1) and the trend figures (Figure 2). This analysis demonstrates a distinct rising trend in academic production during this time, highlighting the dynamic evolution of teaching methods as a research emphasis. The increasing number of articles and their citation impact reflect the expanding understanding of how creative teaching practices affect learning outcomes, student engagement, and the overall efficacy of physical education programs.

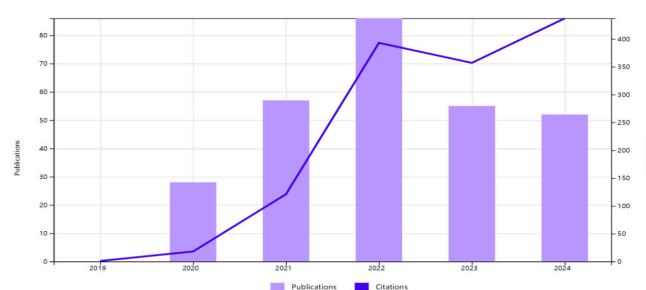
**Fig. 1.** PRISMA Flowchart

Between 2020 and 2024, there will be a notable increase in research on physical education teaching approaches, according to the trend analysis based on data from 278 articles in the Web of Science database. Publications peaked at 86 in 2022, while total citations rose from 18 in 2020 to 437 in 2024. This growth is a result of more academics concentrating on the creation and evaluation of creative physical education teaching methods. The research's scholarly impact is further highlighted by its average citation rate of 4.79 per article and H-index of 17.

A dynamic change in publishing and citation activity over time is revealed by the analysis. For example, citation rates increased even until 2022, despite a minor decline in publications, suggesting that prominent works released

earlier were still of relevance. This pattern implies that research on physical education teaching strategies is having a lasting effect that appeals to both researchers and teachers. It also emphasizes how interdisciplinary techniques are increasingly being incorporated to improve physical education's efficacy.

All things considered, the increasing trend in citations and the consistent output of publications show that the significance of instructional strategies in physical education is becoming increasingly recognized. This development shows a wider understanding of their contribution to raising academic performance, student involvement, and overall development. The study lays the groundwork for future research that expands on current understanding while tackling new issues in the field by recognizing these trends.

**Fig. 2.** Quantity of publications and citations between 2020 and 2024

Results

Performance Analysis

Documents

With 116 citations, Demchenko et al.'s (2021) most referenced study looks at how future teachers are trained in inclusive teaching methods. The substantial influence of this study highlights its contribution to the development of inclusive physical education approaches. The application of IoT technology in physical education is the subject of another well-known paper, Ding et al. (2020), which has 71 citations and emphasizes the growing significance of digital integration in teaching methods. Similarly, with 41 citations, Segura-Robles et al. (2020) investigate the efficacy of gamification and flipped learning strategies. Together, these pieces show how pedagogy, technology, and inclusivity interact to create creative teaching strategies, offering a solid basis for future research in the area.

Source Analysis

Sustainability and Frontiers in Psychology are the most influential publications in this topic, each contributing 11 documents, according to source analysis with a threshold of 44 citations. Together, these journals have received 66 and 95 citations, respectively, indicating their important contribution to the advancement of physical education teaching techniques research. Other well-known sources are Retos (48 citations) and the International Journal of Environmental Research and Public Health (93

citations). These articles connect physical education, health, environmental sustainability, and creative teaching techniques, reflecting the interdisciplinary approach of contemporary studies. These contributions highlight the growing influence and scholarly interest in this field of study.

Author Analysis

According to the author's analysis, Feu and Ibanez are important contributors to the study of physical education teaching strategies, with a threshold of 66 total link strength. Together, their work has received 115 citations, highlighting their impact on cutting-edge teaching techniques. With an emphasis on gender-specific methods, García-Ceberino has made significant contributions and received 79 citations. Similarly, with 48 citations to her name, D'Elia has pioneered performance-based teaching approaches. Through their insights into inclusive, successful, and student-centered teaching methods, these authors have had a substantial impact on the scholarly conversation. Their work still forms the basis for investigating novel patterns and tackling issues in the area.

Organization Analysis

The University of Extremadura is the leading institution in physical education research, contributing 9 papers with 117 citations, based on a citation criterion of 77. With 7 publications and 83 citations, the University of Granada comes in second, demonstrating its significant contributions to interdisciplinary approaches. Another important contributor is the University of Salerno, which has produced eight papers with forty-eight citations, demonstrating its

commitment to cutting-edge teaching methods. In order to improve the caliber of physical education teaching procedures, these schools prioritize collaboration and integrate contemporary ideas, promoting sustainable practices and captivating educational frameworks. When taken as a whole, their contributions support international initiatives to improve teaching methods in this area.

Country Analysis

With 130 publications and 538 citations, China tops the field based on a threshold of 46 documents, indicating its significant influence and dedication to furthering physical education research. With 44 publications and 367 citations, Spain comes in second, emphasizing its emphasis on creative and sustainable teaching strategies. Diverse viewpoints on combining technology and pedagogy are contributed by other nations, including the USA, Italy, and South Korea. These countries are essential in advancing multidisciplinary research, tackling issues, and enhancing the international conversation on physical education. Their combined efforts highlight how crucial regional and cultural diversity is to improving teaching strategies and advancing sustainable education globally.

Co-Citation Analysis

Ten significant papers that explore important topics in physical education, such as curriculum creation, policy enactment, and pedagogical practices, are highlighted by the co-citation analysis, which has a threshold of 46 citations. These publications are compiled in Table 2, where Dyson et al. (2004) rank best with 9 citations and the highest total

Table 2. Co-citations (Top 10 Articles)

Rank	Authors	Title	Citations	Total Link Strength
1	Dyson et al.(2004)	The more things change the more they stay the same: Factors influencing teachers' interpretations and delivery of national curriculum physical education.	9	47
2	Bailey et al.(2009)	Physical education curriculum reform in China: a perspective from physical education teachers.	8	38
3	Ding et al.(2020)	Enabling curriculum change in physical education: the interplay between policy constructors and practitioners.	8	3
4	Mesquita et al.(2012)	Curriculum, pedagogy and assessment: three message systems of schooling and dimensions of quality physical education.	7	45
5	Gil-Arias et al.(2017)	Points of tension and possibility: boundaries in and of physical education.	7	35
6	Hastie & Casey.(2014)	"There is new wording, but there is no real change in what we deliver": Implementing the new National Curriculum for Physical Education in England.	7	32
7	D'Elia et al.(2019)	From policy to pedagogy: prudence and precariousness; actors and artefacts.	7	15
8	Miller.(2015)	Breaking and making curriculum from inside 'policy storms' in an Australian pre-service teacher education course.	6	37
9	Guthold et al.(2020)	Curriculum interpretation and policy enactment in health and physical education: researching teacher educators as policy actors.	6	28
10	Goodyear&Dudley.(2015)	Teacher voice and ownership of curriculum change.	6	24

link strength (47), indicating their significant influence. While Mesquita et al. (2012) discuss how curriculum, pedagogy, and assessment interact to improve the quality of education, Bailey et al. (2009) investigate curriculum reform in China. When taken as a whole, these seminal studies give a critical lens through which to evaluate how policy directives influence educational practices and results, providing important insights into the development of physical education teaching approaches.

Numerous publications go into great detail about the difficulties teachers encounter when implementing policies and the complications of curriculum transformation. Hastie and Casey (2014) examine the gap between curriculum revisions and their actual implementation, highlighting how superficial adjustments frequently have no lasting effect on instructional strategies. Similarly, Gil-Arias et al. (2017) highlight how novel teaching approaches, such as hybrid TGfU-Sport Education, can improve student engagement by focusing on their motivational impacts. Ding et al. (2020) highlight the complex link between policy architects and educators by discussing how practitioners translate policy mandates into workable methods. Together, these papers provide insight into the challenges, possibilities, and flexible approaches associated with managing curriculum change.

By examining teacher responsibilities and worldwide educational trends, the remaining research broaden the conversation. Miller (2015) emphasizes resilience and flexibility while highlighting the ways in which policy “storms” impact pre-service teacher preparation. An international viewpoint is offered by Guthold et al. (2020), who examine trends in teenagers’ lack of physical exercise and the consequences for curriculum design. Goodyear and Dudley (2015) emphasize the value of student-centered approaches to create dynamic learning environments and support teacher ownership in curriculum creation. When taken as a whole, these pieces offer a thorough foundation for comprehending how curriculum regulations, instructional strategies, and teacher agency interact to influence the changing field of physical education.

Co-Citation Analysis by Clusters

By grouping the corpus of research into five different theme clusters—Red, Green, Blue, Yellow, and Purple—

the co-citation analysis of physical education teaching approaches, as shown in Figure 3, provides important insights. A specialized field of study exploring distinct facets of curriculum design, assessment, and teaching is represented by each cluster (Table 3). This classification gives researchers a thorough grasp of the area, enabling them to identify knowledge gaps in previous research, create targeted teaching tactics, and create novel approaches that meet the demands of a wide range of learners. By tackling these theme clusters, the analysis supports the larger goal of improving physical education to meet modern educational difficulties and makes a substantial contribution to the advancement of good teaching techniques.

With 16 articles, Cluster 1 is the largest and focuses on creating and implementing cutting-edge physical education curricula and pedagogical approaches. The revolutionary potential of cooperative learning models and curricular reforms is shown in foundational publications like Bailey et al. (2009) and Dyson et al. (2004), which show how they improve student engagement and learning results. In order to make sure that teaching strategies meet the various needs of students, other important research, such as Metzler (2017), investigate instructional models that place a high priority on inclusivity, flexibility, and skill development. Additionally, this cluster looks at sociocritical reflections that support equity and student-centered methods, such as those found in Landi et al. (2016). Collectively, these studies highlight how important it is to match pedagogy to the changing needs of education in order to create more efficient and significant learning opportunities.

Cluster 2, which consists of 11 articles, is centered on using evidence-based approaches to maximize teaching effectiveness and analyze learning outcomes. Strong evaluations of game-centered and hybrid educational models are offered by Mesquita et al. (2012) and Miller (2015), who demonstrate how these approaches can enhance students’ decision-making, abilities, and general performance. To improve teaching effectiveness, Feu et al. (2019) stress the value of organized task planning and keeping an eye on both internal and external demands. In order to provide a more accurate assessment of students’ development, Oslin et al. (1998) introduced assessment methods such as the Game Performance Assessment Instrument (GPAI). In order to improve teaching methods and attain quantifiable learning

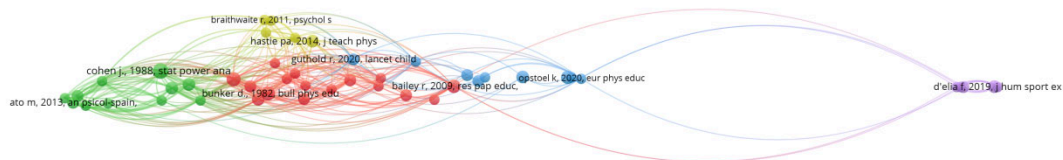


Fig. 3. Co-citations Analysis (VOSviewer Visualisation)

Table 3. Co-citation Cluster

Cluster No and Colour	Cluster Labels	No. of Articles	Representative Publications
Cluster 1 (Red)	Curriculum and Pedagogical Innovation	16	Bailey et al.(2009); Dyson et al.(2004); Gil-Arias et al.(2017); Goodyear& Dudley(2015); Landi et al.(2016); Metzler (2017); Casey & Goodyear (2015); Ryan (2017);
Cluster 2 (Green)	Assessment and Learning Outcomes	11	Mesquita et al.(2012); Miller.(2015); Feu et al.(2019); García-Ceberino et al.(2020); Oslin et al.(1998);
Cluster 3 (Blue)	Technology Integration in Physical Education	9	Ding.(2020); Hinojo Lucena et al.(2020); Guthold et al.(2020); Da-Wei et al.(2018); García-Castejón et al.(2021); Opstoel et al.(2020);
Cluster 4 (yellow)	Motivational and Responsibility Models	5	Hastie & Casey (2014); Pozo et al. (2018); Braithwaite et al.(2011);
Cluster 5(purple)	Teacher Training and Curriculum Design	5	D'Elia(2019); D'Elia (2020); D'Elia et al. (2020);

objectives in physical education, this cluster highlights the need of evaluation by fusing theoretical understanding with real-world applications.

Cluster 3, which has 9 articles, examines how technology is changing physical education teaching strategies. The use of digital tools like virtual reality and flipped learning models to improve student engagement and learning results is highlighted by Ding et al. (2020) and Hinojo Lucena et al. (2020). In their analysis of the role of technology in addressing the trends of physical inactivity among adolescents, Guthold et al. (2020) offer a global approach. Research on hybrid educational programs that combine game-based learning with social responsibility concepts was conducted by García-Castejón et al. in 2021. The combined findings of these research highlight the increasing significance of incorporating digital platforms and multimedia resources to update instruction, encourage student engagement, and satisfy changing learning demands.

Cluster 4, which has 5 articles, focuses on methods for encouraging students to be motivated and to develop their sense of personal and social responsibility. In their analysis of fidelity in the use of model-based practices, Hastie and Casey (2014) emphasize the importance of these practices in fostering uniform teaching standards. Braithwaite et al. (2011) and Pozo et al. (2018) examine how well responsibility-based programs and motivational climate interventions promote enthusiastic student engagement and individual development. This cluster emphasizes the social and psychological aspects of education, with special emphasis on interventions that include students as active members of their communities as well as learners. Collectively, these findings support all-encompassing strategies that take into account students' emotional and cognitive needs.

The importance of curriculum design and teacher preparation in raising the efficacy of physical education is emphasized in Cluster 5, which consists of 5 items. D'Elia et al. (2020) investigate how teachers view curriculum objectives, emphasizing how teaching objectives relate to primary school pupils' developmental requirements. Other research, like D'Elia (2019), focus on creating age-appropriate lesson plans that incorporate contemporary pedagogical ideas. This cluster emphasizes how crucial it is for educators to pursue ongoing professional development in order to ensure that they have the abilities and know-how necessary to successfully connect policy and practice.

In order to develop dynamic and effective physical education programs that satisfy a range of learner needs and further the more general objectives of educational reform, these studies seek to develop teacher competency and creativity.

Co-Occurrence Analysis

Using a threshold of 61, the co-occurrence analysis finds 1,050 terms that generate 602 links with a total link strength of 956. This network emphasizes the interconnection of study subjects by highlighting important thematic areas in physical education teaching approaches. With 71 occurrences and the greatest total link strength of 188 among the top 15 keywords, "physical education" stands out for its crucial importance in the literature. Words like "students," "teaching methods," and "motivation," which highlight the emphasis on student engagement and pedagogical innovation, are also important. Future research in the topic will be guided by this analysis, which offers an organized summary of the main study issues and how they relate to one another.

Table 4. The 15 most frequent keywords in the co-occurrence analysis

Rank	Keyword	Occurrences	Total Link Strength
1	physical education	71	188
2	students	34	107
3	physical-education	22	45
4	teaching methods	21	47
5	teachers	20	83
6	Performance	19	66
7	Education	19	52
8	motivation	18	61
9	sport	17	67
10	impact	15	51
11	sport education	14	66
12	model	14	55
13	teaching method	12	37
14	children	11	55
15	sports	10	23

Table 5. Co-word Analysis on relationship between physical education and teaching methods.

Cluster No and Colour	Cluster Label	Number of Keywords	Representative Keywords
1 (Red)	Sports and Interventions	12	“sport,” “sport education,” “children,” “impact,” “intervention,” “knowledge,”
2 (Green)	Game-Based Learning and Methodology	10	“games,” “learning,” “teaching method,” “basketball,” “experience,”
3 (Blue)	Performance and Motivation	9	“performance,” “motivation,” “design,” “experiences,” “gamification,”
4 (Yellow)	Education and Skills Development	7	“education,” “skills,” “satisfaction,” “secondary education,”
5(purple)	Teacher Roles and Health Promotion	6	“teachers,” “health,” “physical-activity,”

technology-driven and interactive methods to engage pupils and maintain their interest. The increasing focus on individualized learning environments that meet the needs of each individual student and promote active engagement is reflected in this cluster. Teachers can promote changes in the cognitive and physical components of education by implementing cutting-edge tactics like performance monitoring and incentive tools, which will ultimately create a more comprehensive learning environment.

Cluster 4, which has 7 keywords, is about how education should be in line with skill development and learner satisfaction, particularly in secondary education. The words “education,” “skills,” and “satisfaction” highlight the importance of developing well-rounded and efficient teaching frameworks. This cluster also looks at the relationship between skill development and academic achievement, making sure that pupils are ready for both intellectual and physical difficulties. Prioritizing skill development and satisfaction allows educators to create programs that enhance students’ educational experiences by fostering long-term engagement, resilience, and confidence in addition to developing motor abilities.

Cluster 5, which has 6 keywords, emphasizes how important educators are in encouraging physical activity and health in classrooms. The terms “teachers,” “health,” and “physical-activity” highlight the importance of both teaching and the formation of wholesome habits that last a lifetime. According to this cluster, it is crucial to give teachers the tools they need to incorporate health education into physical education classes so that students can comprehend and value active lifestyles. Teachers may encourage students to place a higher priority on their physical and mental health by serving as role models and facilitators, ultimately resulting in a generation that is healthier and more knowledgeable.

Discussion

Significant trends in the study on physical education (PE) teaching strategies from 2020 to 2024 are shown by this bibliometric analysis. The report notes a notable rise in citations and publications, which peaked in 2022 and highlights the rising interest of academics in cutting-edge PE pedagogies. Key individuals like Feu and Ibanez, as well as organizations like the University of Extremadura, have become well-known, and their work is regularly recognized. The convergence of technology and inclusion is a prominent

issue in high-impact research, such as those by Demchenko et al. (2021) on inclusive education and Ding et al. (2020) on IoT integration. Five theme clusters, such as curricular innovation, technological integration, and motivational tactics, are further defined by co-citation and co-word analyses, which illustrate the field’s dynamic evolution. All of these results point to a trend in physical education toward inclusive, technology-enhanced, student-centered teaching approaches.

The findings are consistent with earlier research that highlights the transformative potential of student-centered and technology-driven approaches in physical education, including that conducted by García-Ceberino et al. (2020) and Goodyear and Dudley (2015). But this study also reveals new elements that weren’t as noticeable in previous studies, like hybrid models that combine TGfU and sport education. This study’s focus on recent years (2020–2024), which capture post-pandemic movements toward blended learning and digital resources, may be the cause of discrepancies with previous work. For example, Zheng et al. (2021) observed difficulties with blended learning during COVID-19, but our results show that it has since been normalized and improved. These variations highlight how environmental and chronological factors influence research trends.

Thematic clusters found in this study show how PE research has matured, with a focus on comprehensive student development and interdisciplinary integration (such as technology and psychology). According to Ryan’s (2017) theory, the popularity of phrases like “gamification” and “motivation” points to a paradigm shift toward engagement and lifelong learning. On the other hand, the continuation of “knowledge silos” in some subfields, such teacher preparation, suggests unequal advancement. Influential publications like Dyson et al. (2004), which continue to influence curriculum frameworks, are revealed by this study’s co-citation network, indicating that core theories are still important while being adjusted to meet modern demands.

The results provide policymakers and educators with useful information. According to García-Castejón et al. (2021), hybrid models are successful, which supports their broader use in physical education programs. However, targeted professional development and equitable resource allocation are necessary to address issues like teacher readiness (García-Espinosa et al., 2020) and resource inequities (Hinojo Lucena et al., 2020). As demonstrated by the prominent roles played by Chinese and Spanish

universities, institutions should place a high priority on collaborations in order to promote innovation. In order to ensure successful adoption, the emergence of digital tools also necessitates updated infrastructure and training.

The scope of this study may be limited by its rejection of non-English literature and gray materials, even though its usage of the Web of Science guarantees rigor. Although VOSviewer offers strong visuals for co-citation and co-word analysis, it may miss subtle patterns that can be found using mixed-methods approaches. The 2020–2024 period may not accurately represent long-term changes, but it does capture recent patterns. As proposed by Sargent and Casey (2021), future research might use qualitative techniques to contextualize bibliometric findings or broaden data sources to include Scopus and ERIC.

There are various restrictions on this study. First, the representation of non-Western research may be skewed due to its reliance on English-language publications. Second, books and conference proceedings are not included in the emphasis on journal articles, which may leave out important work. Third, established authors may be given preference over up-and-coming voices based on bibliometric metrics like citation counts. Lastly, the post-pandemic rapid evolution of PE pedagogies calls for constant updating to reflect new developments.

Longitudinal patterns should be investigated in future studies to confirm the viability of popular trends like gamification and the Internet of Things. As demonstrated by Perdimma et al. (2022), bibliometrics and content analysis together may enhance knowledge of pedagogical efficacy. To guarantee global diversity, research into underrepresented areas and unconventional publications is also required. Last but not least, Zhou et al. (2023) point out that multidisciplinary partnerships may help close the gap between theory and practice and promote creativity in PE teaching approaches.

Conclusions

The research landscape of physical education (PE) teaching methods from 2020 to 2024 was extensively analyzed using bibliometric techniques in order to pinpoint important trends, seminal publications, and developing themes. Through an analysis of 278 articles from the Web of Science database, the study offers a thorough picture of the development and intellectual framework of the area.

Three main conclusions were drawn: (1) A change toward student-centered pedagogies was reflected in the thematic clusters, which showed a strong emphasis on curriculum innovation, technological integration (such as IoT, gamification), and motivational techniques. (2) Research production was dominated by China and Spain, with writers like Feu and Ibanez influencing academic discourse and universities like the University of Extremadura leading in citations. (3) Co-citation analysis brought to light both new hybrid approaches (e.g., TGfU-Sport Education) and established frameworks such as the curricular model developed by Dyson et al.. These findings highlight the field's rapid shift toward digital adaption and inclusion.

The study provides useful information for educators and legislators, highlighting the necessity of equitable resource distribution and professional development in technology-enhanced instruction. Future study could broaden data sources (e.g., Scopus) and include qualitative

methodologies, as limitations include the exclusion of non-English literature and reliance on citation-based measures. This bibliometric analysis provides a fundamental resource for developing evidence-based pedagogies and encouraging interdisciplinary collaboration as physical education continues to address global issues like physical inactivity.

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Conflict of Interest

The author has no conflict of interest.

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За межами навчального процесу: Мапування глобальних тенденцій у методах викладання фізичного виховання шляхом проведення бібліометричного аналізу

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 9 с., 5 табл., 4 рис., 39 джерел.

Мета дослідження. Орієнтуючись на зростаючу важливість новітніх педагогічних методик, що включають технології, інклюзивність та студентоцентричні підходи, у цьому бібліометричному дослідженні вивчаються розвиток та сучасні тенденції у методах викладання фізичного виховання (ФВ) у період з 2020 по 2024 рік. Щоб скерувати подальші дослідження та практичну діяльність, мета дослідження полягала у мапуванні інтелектуальної структури галузі, визначенні вагомих авторів та виокремленні актуальних тематик.

Матеріали та методи. У дослідженні використовувалися бібліометричні методології, включаючи коцитування та аналіз співвідношення слів, з метою ретельної оцінки публікаційних патернів, авторитетних робіт та тематичних кластерів на основі даних із 278 статей, отриманих з наукометричної бази Web of Science.

Результати. Результати показують помітне зростання кількості наукових публікацій, яке досягло максимуму в 2022 році та було переважно зумовлене роботами вчених з Китаю та Іспанії. Серед ключових гравців — такі університети, як Університет Естремадури, та провідні автори, серед яких Фейу та Ібаньес. У тематичних кластерах висвітлено домінуючі фокуси, як-от інновації в навчальних програмах, технологічна інтеграція (наприклад, гейміфікація та Інтернет речей) й мотиваційні техніки. Взаємодія педагогіки та технологій підкреслюється високоефективними дослідженнями, зокрема тими, що були проведені Демченком та іншими вченими щодо інклюзивного навчання, а також Дінгом та ін., у роботах яких розглядалося питання цифрових інструментів. Субтеми, як-от роль викладачів у сприянні здоровому способу життя та ігрове навчання, визначаються додатково за допомогою аналізу співвідношення слів.

Висновки. Результати цього дослідження підкреслюють перехід до мультидисциплінарних та гібридних підходів, що відповідає загальносвітовим тенденціям в освіті. Однак все ще існують такі проблеми, як нерівність у розподілі ресурсів та підготовленість викладачів. З метою подолання розриву між теорією та практикою, за результатами дослідження було рекомендовано зосередитися на професійному розвитку, справедливому розподілі ресурсів та проведенні додаткових досліджень. Представлене дослідження є фундаментальним джерелом інформації, що сприяє спільним інноваціям у цій галузі та вдосконаленню науково обґрунтованих педагогічних методів фізичного виховання.

Ключові слова: фізичне виховання, методи навчання, бібліометричний аналіз, гібридні моделі, освітні технології.

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Review Article

Towards Inclusive Physical Activity: A Systematic Review of Scopus Evidence on Multidimensional Barriers in Physical and Intellectual Disabilities

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Abstract

Objectives. The study aimed to systematically analyze barriers to physical activity (PA) among individuals with physical and intellectual disabilities, integrating the COM-B model and Social Determinants of Health (SDH) framework to identify universal and disability-specific challenges.

Materials and methods. The present research involved a PRISMA-guided systematic review of 14 Scopus-indexed studies published between 2021 and 2025 from high- (HICs) and low-middle-income countries (LMICs). Thematic synthesis categorized barriers into environmental/structural, intrapersonal, and sociocultural domains.

Results. The results revealed environmental/structural barriers as predominant (10 studies), including transportation limitations (29% in Norway), inaccessible facilities (91% inactivity in Canadian children), and institutional resource gaps. Intrapersonal barriers (4 studies) included motivation deficits and gender stigma (8 unique barriers for women with physical disabilities). Distinct challenges were identified: individuals with physical disabilities faced fatigue ($\beta = -0.34$, $p < 0.001$) and chronic pain, while individuals with intellectual disabilities encountered caregiver dependency and cognitive limitations. Geographic disparities highlighted infrastructural barriers in HICs (e.g., Belgium's adaptive program gaps) versus motivational/resource challenges in LMICs (e.g., 0% PA compliance among Turkish mothers).

Conclusions. The findings of this study underscore the need for tailored, multi-level interventions addressing disability-specific barriers and systemic inequities. Policy priorities include infrastructure investment, caregiver training, and stigma reduction to align with SDGs 3 (Health) and 10 (Reduced Inequalities). Cross-sector collaboration and context-driven strategies are critical to operationalize inclusive PA frameworks globally.

Keywords: physical activity, disability and health equity, environmental accessibility, COM-B model, inclusive policy, sustainable development goals (SDGs).

Introduction

Lack of physical activity is a fundamental problem faced by people with disabilities worldwide. Based on data from the World Health Organization (WHO, 2011, 2022)

and the Health and Disability Data System (DHDS, 2020), it is estimated that 30–58% of this population does not meet the minimum physical activity (PA) recommendations, with inactivity rates exceeding the general population by 1.5–3 times. This gap stems not only from individual health conditions but is also influenced by systemic inequities such as inaccessible environments, social stigma, and inconsistent policy implementation (Naud et al., 2019; Southby et al., 2019). These challenges directly hinder progress towards

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the United Nations Sustainable Development Goals (SDGs) for equitable health outcomes and inclusive societies (UN, 2015), which requires urgent cross-sectoral collaboration.

Previous research has mapped the various barriers to physical activity among specific disability groups. In people with physical disabilities, the main structural barriers are inadequate infrastructure and limited transportation (M. Bloemen et al., 2017; M. A. T. Bloemen et al., 2015). In contrast, in individuals with intellectual disabilities, the most common problems are dependency on caregivers and social marginalization (Bondár et al., 2020; Dairo et al., Sutherland et al., 2021). Recent scholarship increasingly documents gendered dimensions of exclusion, demonstrating that women with disabilities confront intersecting obstacles such as discrimination and gender-insufficient program designs (Olasagasti-Ibargoinen et al., 2023; Tuncay & Sarman, 2023). Theoretical models, including the COM-B framework (capability, opportunity, motivation-behavior) and Social Determinants of Health (SDH), have enhanced insights into the interplay between individual capacities, environmental contexts, and systemic inequities in restricting PA engagement (Ashadi, 2024; McDermott et al., 2022). Nevertheless, significant knowledge voids remain unresolved.

First, comparative analyses of barriers across disability types remain scarce, obscuring shared and distinct challenges. For instance, while environmental inaccessibility similarly affects individuals with physical and intellectual disabilities (Devarajan et al., 2020; Farrell, & Giles, 2022), their interaction with disability-specific factors—such as chronic pain in physical disabilities versus cognitive dependency in intellectual disabilities—is underexplored. Second, studies predominantly originate from high-income countries (HICs; e.g., Canada, Norway), neglecting low- and middle-income countries (LMICs) where 80% of the global disability population resides (WHO, 2024). This geographic imbalance limits insights into how socioeconomic and cultural contexts shape PA participation, particularly in resource-limited settings. Third, existing interventions often prioritize isolated dimensions (e.g., structural or behavioral), lacking integrative frameworks that address intersections of disability type, gender, and sociocultural norms (Shea et al., 2022).

This study addresses these gaps by systematically analyzing PA barriers across physical and intellectual disabilities through a multidimensional lens. Integrating the COM-B model and SDH framework, we propose a typology of universal and disability-specific barriers, informed by 14 global studies (2021–2025) spanning HIC and LMIC contexts. Our analysis advances three contributions: (1) a cross-disability classification of barriers, identifying environmental/structural (e.g., transportation gaps), intrapersonal (e.g., motivation), and sociocultural (e.g., gender stigma) determinants; (2) evidence-based policy recommendations targeting micro- (caregiver training), meso- (community programs), and macro-level (infrastructure funding) reforms; and (3) a foundation for operationalizing the UN Convention on the Rights of Persons with Disabilities through cross-sector collaboration. By bridging theoretical and practical divides, this review informs equitable PA promotion strategies aligned with SDGs 3 (Health) and 10 (Reduced Inequalities).

Materials and Methods

Study Design

This systematic review was designed to identify thematic syntheses and publication trends related to physical activity barriers among individuals with physical and intellectual disabilities. The analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Moher et al., 2009). The Scopus database was selected as the primary source due to its credible indexing and lower risk of duplication or predatory articles compared to Google Scholar (Lasda Bergman, 2012; Mendes Rocha et al., 2023).

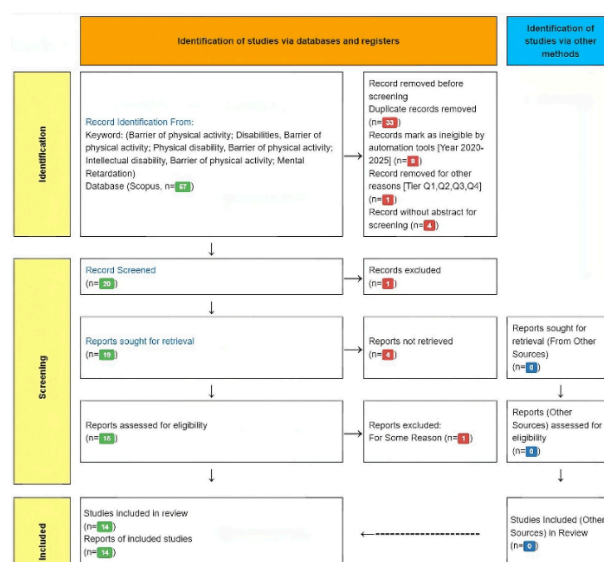


Fig 1. Flowchart diagram illustrating the study selection procedure following PRISMA guidelines

Eligibility Criteria

The study selection process applied the following eligibility criteria: (1) empirical investigations published in Scopus-indexed journals (all quartiles, Q1-Q4) from 2020 to 2025; (2) English-language articles with full open access; and (3) studies that explicitly examine barriers to physical activity in individuals with physical or intellectual disabilities. Exclusion criteria were carried out by eliminating studies with limited text accessibility, publications behind a paywall or restricted access, and papers that did not focus on barriers to physical activity.

Procedure

The analysis adhered to the four-stage PRISMA framework. The identification phase began with a search in the Scopus database using the keywords “Barrier of physical activity”, “Physical disability”, “Intellectual disability”, and “Mental Retardation”, yielding 67 initial articles. During the screening phase, 33 articles were removed due to duplication, 14 articles were excluded for not meeting inclusion criteria (open access and disability focus), 9 articles fell outside the 2020–2025 publication range, 1 article did

not meet journal tier criteria (Q1–Q4), and 4 articles lacked abstracts, resulting in 20 eligible articles. In the evaluation phase, 1 irrelevant article, 4 articles with unavailable full texts, and 1 article with methodological bias were excluded, leaving 14 final studies for in-depth analysis. During the data analysis phase, a thematic synthesis integrating qualitative and quantitative findings was conducted to identify primary physical activity barriers—interpersonal, intrapersonal, and environmental/structural—while also examining differences between physical and intellectual disabilities.

Result

Profile of Physical Activity Barriers

Research on barriers to physical activity (PA) among individuals with physical and intellectual disabilities has predominantly been conducted in Europe, the Americas, Asia, and Australia. Methodologies such as systematic reviews, cross-sectional studies, surveys, and cohort analyses were most frequently employed, with a balanced composition of quantitative and qualitative data. Target demographics

Table 1. Disability research synthesis: methods, populations, barriers, and outcomes

No	Authors	Country	Research Methods	Target Population	Disability Type	Dominant Barriers	Result
1	Liu et al., 2025	China	Systematic review	Adolescents	Multiple disability	Environmental/ Structural Barriers	The thematic synthesis revealed 19 themes, including a unique “Special factor” and three interaction phases among school administrators, staff, and students with disabilities, emphasizing the need for tailored strategies to support participation in physical activities
2	Michalsen et al., 2024	Norway	Cross-sectional	Adults	Intellectual	Environmental/ Structural Barriers	The study revealed 36% of 213 Norwegian adults with ID were sedentary. Primary barriers included transportation limitations (29%), health conditions (26%), and lack of day-center activities (17%). Significant correlations emerged between sedentary behavior and older age ($p=0.002$), mobility impairment ($p<0.001$), and epilepsy ($p=0.003$).
3	Ma et al., 2024	China; USA; New Zealand	Bibliometric review	Children and Adolescents	Multiple disability	Environmental/ Structural Barriers	The study analyzed 1,308 articles, revealing key research hotspots such as interventions and programs aimed at enhancing physical activity among disabled youth, along with their collaborative networks
4	Wildekamp et al., 2024	Netherlands	Cohort	Adults	Physical	Environmental/ Structural Barriers	Perceived PA barriers decreased significantly during the transition from rehabilitation to community-based PA, with capability and motivation barriers showing the strongest negative associations with PA levels. Tailored counseling during rehabilitation may mitigate barriers and promote sustained PA
5	Ascondo et al., 2023	Spain	Survey	Adolescents and Adults	Multiple disability	Intrapersonal Barriers	The findings indicate that personal barriers are more significant than environmental ones, with women perceiving more barriers than men. People with physical disabilities focus on physical improvement, while those with intellectual disabilities prioritize leisure and social aspects
6	Olasagasti-Ibargoien et al., 2023	Spain	Systematic review	Adults	Physical	Intrapersonal Barriers	The review found eight distinct types of barriers that women with physical disabilities face in engaging in physical activities. These barriers are influenced by gender, indicating that social environments play a crucial role in participation

Table 1 (continued)

No	Authors	Country	Research Methods	Target Population	Disability Type	Dominant Barriers	Result
7	Boucher et al., 2022	Canada	Interview	Children	Intellectual	Intrapersonal Barriers	The research identified four key themes: intrapersonal barriers, interpersonal barriers, intrapersonal facilitators, and interpersonal facilitators, highlighting factors that influence physical activity engagement among autistic youth with mild intellectual disabilities
8	McDermott et al., 2022	United Kingdom	Focus group discussions	Adolescents	Intellectual	Environmental/ Structural Barriers	The study identified individual (physical/psychological capabilities), interpersonal (social support), and environmental (school resources) factors influencing PA, highlighting the need for tailored, co-produced interventions within school systems
9	Yu et al., 2022	China	Survey/ observational methods	Children and Adolescents	Intellectual	Environmental/ Structural Barriers	The review included 32 studies, revealing 34 factors influencing physical activity. Key barriers included disability-specific issues and lack of support, while facilitators included high self-efficacy and parental involvement
10	Özkan, R. S., & Numanoglu-Akbaş, 2022	Turkey	Cross-sectional	Caregivers	Physical	Environmental/ Structural Barriers	The study found that mothers of children with mild motor disabilities had higher physical activity levels compared to those with moderate-to-severe disabilities. None of the mothers achieved adequate physical activity levels
11	Declerck et al., 2021	Belgium	Survey	Adults	Physical	Environmental/ Structural Barriers	The research highlights significant barriers faced by sports clubs and centers in expanding adaptive physical activity and sports offerings for individuals with physical disabilities, emphasizing the need for targeted interventions to overcome these challenges
12	MacEachern et al., 2021	Canada	Cohort	Children and Adolescents	Multiple disability	Environmental/ Structural Barriers	The study found that 91% of children and adolescents with disabilities did not meet physical activity guidelines, with participation decreasing as age increased. Access to suitable environments was a primary barrier to participation
13	Mckenzie et al., 2021	Australia	Systematic review	Adolescents and Adults	Physical	Intrapersonal Barriers	The review included 19 studies, revealing that social connections and supportive environments are crucial for physical activity participation. An overarching theme of “finding the right balance” emerged, highlighting the importance of capability, opportunity, and motivation in this context
14	Jacinto et al., 2021	Portugal	Systematic review	Adults	Intellectual	Environmental/ Structural Barriers	The review identified five main groups of perceived barriers to physical activity participation: personal (6 topics), family (4 topics), social (13 topics), financial (1 topic), and environmental (1 topic)

primarily included adults, children-adolescents, and adolescents-adults, with limited studies focusing on older adults. Environmental/structural and intrapersonal factors emerged as the primary barriers for both disability groups. Analysis of 14 global studies (2021–2025) revealed complex patterns of PA barriers among individuals with physical and intellectual disabilities.

Environmental/structural barriers dominated (10 studies), particularly related to transportation, adaptive sports facilities, and institutional resource gaps. In Norway, 36% of adults with intellectual disabilities (ID) were physically inactive, with key barriers including transportation (29%), health conditions (26%), and lack of daily center programs (17%) (Michalsen et al., 2024). In Belgium, sports clubs faced significant challenges in providing adaptive PA for individuals with physical disabilities (Declerck et al., 2021). Meanwhile, in Canada, 91% of children and adolescents with disabilities failed to meet PA guidelines, with inadequate environmental access as the primary constraint (Barreno et al., 2021).

Intrapersonal barriers were identified in 4 studies, predominantly linked to motivation, gender-based stigma, and cognitive limitations. Women with physical disabilities in Spain encountered 8 unique gender-based barriers, including social stereotypes and insufficient inclusive facilities (Groenewegen et al., 2021; Smith & Monforte, 2021). For intellectual disabilities, challenges included limited comprehension of PA instructions Click or tap here to enter text. and caregiver dependency (Geuze et al., 2023). Regional variations highlighted significant disparities: developed countries (e.g., Norway, Belgium) prioritized infrastructural limitations, while developing nations (e.g., Turkey) faced motivational and resource-related challenges. In Turkey, mothers of children with severe motor disabilities exhibited notably lower PA levels, with 0% meeting daily recommendations (Özkan & Numanoglu-Akbaş, 2022). A Spanish study (Ascondo et al., 2023) confirmed that personal barriers (e.g., self-perception) were more pronounced among women than men. Furthermore, a bibliometric analysis of 1,308 articles identified school-based interventions as a global research “hotspot.”

Characteristics of Physical Activity Barriers

Individuals with physical and intellectual disabilities share common structural and social barriers, including transportation limitations (29% in Norway) and inadequate adaptive facilities (Carmichael et al., 2023) as well as social stigma—encompassing 8 gender-based barriers faced by women with physical disabilities (Olasagasti-Ibargoiien et al., 2023) and social isolation among those with intellectual disabilities (Sakalidis et al., 2023). Both groups are further impacted by secondary health conditions (e.g., epilepsy, mobility impairments) and low motivation, albeit with differing underlying causes (chronic fatigue vs. diminished self-confidence).

Notably, distinct barriers exist between the two groups. For physical disabilities, key challenges include fatigue ($\beta = -0.34$, $*p < 0.001$), chronic pain, gender-based barriers (Mayo et al., 2019), and age- or health-related declines in physical activity. In contrast, intellectual disabilities are characterized by cognitive limitations, caregiver dependency

(Kreinbucher-Bekerle et al., 2022), and reduced physical activity due to life transitions (MacEachern et al., 2022).

Discussion

Interpretation of Key Findings

These findings align with prior literature acknowledging physical activity (PA) as a critical determinant of well-being for individuals with disabilities (Johnson et al., 2023). However, the analysis identifies two primary gaps: (1) limited exploration of external factors (accessibility, social support) compared to intrapersonal factors, and (2) overrepresentation of studies from high-income countries (Canada, the UK, Australia) with minimal inclusion of low- and middle-income nations (e.g., Turkey) (Declerck et al., 2021). This geographic disparity limits understanding of socioeconomic and cultural contexts influencing participation in resource-poor regions. Methodologically, quantitative approaches (e.g., surveys) dominated for data generalizability (7 studies), while qualitative methods (e.g., in-depth interviews) in 5 studies captured subjective experiences (Boucher et al., 2023; McDermott et al., 2022). Future integration of mixed-methods designs could enrich context-specific intervention evidence.

The findings underscore the multidimensional barriers to PA participation among individuals with disabilities, shaped by structural, intrapersonal, and sociocultural factors. The prominence of environmental/structural barriers—such as transportation limitations, inadequate adaptive facilities, and institutional resource gaps—resonates with the Social Determinants of Health framework, positing health inequities as products of systemic access disparities (Ashadi, 2024). For instance, high sedentariness among Norwegian adults with intellectual disabilities (Michalsen et al., 2024) and 91% non-compliance with PA guidelines among Canadian children with disabilities (MacEachern et al., 2022) reflect how infrastructural inadequacies disproportionately marginalize this population. These results align with global reports advocating inclusive urban planning and policy reforms to address accessibility gaps (Slavici, 2023).

Intrapersonal barriers related to gender stigma and cognitive barriers suggest a close relationship between disability experiences and sociocultural dynamics. A study in Spanish women with physical disabilities (Olasagasti-Ibargoiien et al., 2023) described how gender-driven social norms intensify disability-related challenges, advocating for a feminist disability perspective in the study of physical activity. On the other hand, the dependence of people with intellectual disabilities on caregivers (Jacinto et al., 2021) highlights the need for interventions that prioritize self-determination. The interesting fact that barriers differ between physical and intellectual disabilities—such as fatigue ($\beta = -0.34$, $*p < 0.001$) and chronic pain emerged as major concerns for people with physical disabilities, while cognitive dependence was higher for people with intellectual disabilities—requires a disability-specific approach. These findings are in line with the COM-B framework (Michie et al., 2011), which underlines the importance of strategies to address gaps in abilities, environmental opportunities, and motivational drivers.

Geographic disparities also deserve further attention. High-resource countries such as Norway and Belgium

report systemic barriers such as fragmented daily activity programs, while low-income areas such as Turkey face motivational barriers and resource scarcity (Özkan & Numanoglu-Akbaş, 2022). This contrast highlights the inadequacy of one-size-fits-all interventions and strengthens the argument for context-specific solutions. For example, community-driven school-family partnerships in China (Yu et al., 2022) highlight the potential of local strategies in low-resource settings, while a Dutch rehabilitation program utilizing specialized counseling (Wildekamp et al., 2024) demonstrates the effectiveness of individualized care in a high-capacity system.

In summary, a comprehensive and intersectional approach is needed to reduce barriers to physical activity for populations with disabilities. Policymakers should prioritize investments in implementing inclusive infrastructure and stigma reduction initiatives, while clinicians should integrate disability-responsive practices that address cultural factors. Addressing these challenges can foster equitable PA engagement, which supports the United Nations agenda to reduce health disparities (UN, 2015).

Limitations and Future Directions

Methodological limitations of this study, including its reliance on cross-sectional data collection and self-report measures, limit causal interpretations and may introduce potential recall bias. Additionally, limited representation from low- and middle-income countries (LMICs) and non-English journal sources narrow the applicability of the results, given that approximately 80% of the global population with disabilities live in developing regions (WHO, 2024). Future investigations are recommended to adopt a longitudinal mixed-methods approach to better track temporal patterns and socio-environmental influences. Methodological innovations such as integrating wearable monitoring devices (Dan, 2020) and culturally appropriate intervention models are expected to strengthen empirical validity. There is also an urgent need to examine how global disruptions such as the COVID-19 pandemic—which has been shown to widen physical activity gaps (MacEachern et al., 2022)—impact disability-inclusive PA systems. These insights underscore the importance of multi-layered strategies that address the interplay of structural inequities, social norms, and personal barriers. Conceptual models such as the Australian COM-B (ability, opportunity, motivation-behaviour) framework, which examines the determinants of behaviour holistically (Mckenzie et al., 2021), offer a powerful framework for designing inclusive initiatives.

Future efforts should focus on multimodal interventions combining assistive technologies, community-based training, and family support systems (Knupper, 2018). Expanded research in LMICs—particularly in Africa and South America—is urgently needed to address region-specific barriers, such as limited healthcare access and cultural stigma (Adugna et al., 2020; Magnusson et al., 2021). International cross-sectoral partnerships could facilitate knowledge transfer and local adaptation of evidence-based strategies. Methodologically, integrating quantitative (e.g., longitudinal surveys) and qualitative (e.g., phenomenological studies) approaches will enable holistic analysis of PA barriers.

Physical activity not only enhances physical health but also mitigates social isolation and improves quality of life. Thus, interdisciplinary research spanning public health, psychology, and policy science is essential to design inclusive policies addressing the complex needs of individuals with disabilities (Bailie et al., 2023). Such efforts align with the United Nations Sustainable Development Goals (SDGs) to reduce health inequities and foster equitable participation (UN, 2015).

Conclusion

This systematic review identifies motivation, health status, and facility accessibility as primary determinants of physical activity (PA) participation among individuals with disabilities, with a predominance of evidence from high-income countries. While both physical and intellectual disabilities face comparable structural barriers, their root causes diverge—centering on physiological challenges (e.g., fatigue) in physical disabilities versus cognitive limitations in intellectual disabilities. The integration of quantitative and qualitative methodologies enriches the understanding of these multidimensional barriers. Addressing structural inequities and advancing global inclusion necessitates personalized interventions and cross-sectoral collaboration. Future efforts must prioritize context-driven holistic research frameworks to inform equitable PA promotion strategies for diverse disability populations.

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Conflict of Interest

All authors declare no conflicts of interest.

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На шляху до інклюзивної фізичної активності: Систематичний огляд даних наукометричної бази Scopus щодо багатовимірних бар'єрів при фізичних та інтелектуальних порушеннях

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 1 табл., 1 рис., 50 джерел.

Мета дослідження. Мета дослідження полягала в систематичному аналізі бар'єрів, що перешкоджають фізичній активності (ФА) серед осіб з фізичними та інтелектуальними порушеннями, інтегруючи модель аналізу поведінки СОМ-В (спроможність, можливість, мотивація) та концепції соціальних детермінант здоров'я (СДЗ) для визначення загальних та специфічних проблем, пов'язаних з інвалідністю.

Матеріали та методи. Представлена наукова праця передбачала проведення систематичного огляду за методологією PRISMA щодо 14 досліджень, індексованих у наукометричній базі даних Scopus, які були опубліковані в період з 2021 по 2025 рік і проводилися в країнах з високим рівнем доходу (HIC) та країнах з низьким і середнім рівнем доходу (LMIC). Тематичний синтез класифікував бар'єри за середовищними/структурними, внутрішньоособистісними та соціокультурними сферами.

Результати. Результати показали, що середовищні/структурні бар'єри є переважаючими (10 досліджень), серед яких транспортні обмеження (29% у Норвегії), недоступність об'єктів (91% відсутності активності у канадських дітей) та брак інституційних ресурсів. Внутрішньоособистісні бар'єри (4 дослідження) включали дефіцит мотивації та гендерну стигматизацію (8 специфічних бар'єрів для жінок з фізичними порушеннями). Виявлено окремі проблематичні питання: особи з фізичними вадами стикалися з втомою ($\beta = -0.34$, $p < 0.001$) та хронічним болем, тоді як особи з інтелектуальними вадами зіткнулися з необхідністю допомоги з боку доглядачів та когнітивними обмеженнями. Географічні розбіжності підкреслили інфраструктурні бар'єри в країнах з високим рівнем доходу (наприклад, прогалини в адаптивних програмах Бельгії) порівняно з мотиваційними/ресурсними проблемами в країнах з низьким та середнім рівнем доходу (наприклад, 0% дотримання фізичної активності серед турецьких матерів).

Висновки. Результати дослідження наголошують на необхідності впровадження адаптованих багаторівневих інтервенцій, спрямованих на усунення бар'єрів, пов'язаних з інвалідністю, та системних нерівностей. До пріоритетних політичних завдань належать інвестиції в інфраструктуру, навчання осіб, які доглядають за особами з обмеженими можливостями, та зменшення стигматизації, що узгоджується з цілями сталого розвитку (ЦСР) 3 (Здоров'я) та 10 (Зменшення нерівності). Міжсекторальна співпраця та контекстно-орієнтовані стратегії мають вирішальне значення для операціоналізації інклюзивних концепцій фізичної активності на глобальному рівні.

Ключові слова: фізична активність, інвалідність та рівність у сфері охорони здоров'я, середовищна доступність, модель СОМ-В, інклюзивна політика, цілі сталого розвитку (ЦСР).

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Review Article

Applying Resisted Sprint Protocols for Acceleration Improvement in Team Sports: Evidence from a Systematic Review

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Abstract

Background. In team sports, decisive actions such as anticipating opponents' scheme executions and realizing game objectives depend on the ability to accelerate rapidly and maintain high speeds, often under external resistance and during changes of direction. Resisted sprint training has been proposed to simulate these conditions and to enhance the sprint-specific neuromuscular qualities required in competitive settings.

Objectives. This study aimed to critically examine, through a systematic approach, the various methodologies of resisted sprinting (sled training, motorized systems) applied in team sports, in order to acquire practical recommendations to optimize acceleration velocity and explosive power.

Materials and methods. A PRISMA-guided literature review was performed on Scopus (2020–2025) using the keywords “resisted sprinting”, “sled training” and “sprint with overload”. After screening 103 records and assessing 56 full-text articles, 14 studies (13 original research articles and 1 meta-analysis) were included based on language, article type and relevance to the topic.

Results. According to the results obtained, it has been determined that protocols employing sled resistance corresponding to a 50 % velocity decrement or loads of approximately 10–13 % of body mass led to significant improvements in acceleration over 5–30 m, horizontal force production and maximal power output. Profiling tools (e.g., the 1080 Sprint system) proved valid and reliable, while force–velocity profiling revealed load-specific adaptations that support individualized loading based on athlete role, age and sport discipline.

Conclusions. The findings suggest that resisted sprint training is effective in improving acceleration and neuromuscular power in team sports. Optimal outcomes depend on precise load calibration, the use of valid profiling instruments, and personalized programming tailored to the specific needs of athletes and their disciplines.

Keywords: resisted sprinting, sled training, force–velocity profiling, acceleration, team sports.

Introduction

In team sports, athletic performance is the result of a combination of physical capacities, technical skills and tactical elements, which together determine competitive success across different disciplines (Bangsbo, 2015). In particular, in sports such as soccer, basketball, handball and rugby, performance effectiveness depends on athletes' ability to execute specialized technical actions and to sustain high-intensity efforts—characterized by rapid accelerations, changes of direction, repeated sprints and explosive actions

such as jumps and tackles (Cusano et al., 2019; D'Elia et al., 2021). Within this context, the capacity to generate high levels of power during performance (Cormie et al., 2011; Cronin & McGuigan, 2011) is a fundamental element in protocols aimed at improving high-intensity, sport-specific movements (Raiola et al., 2025; D'Isanto et al., 2025). The ability to reach high running velocities in short time frames is considered crucial for competitive performance, directly influencing actions such as anticipating opponents, gaining space and finishing plays (Hader et al., 2015). However, sprints in team sports rarely occur under linear, uniform conditions; they frequently involve obstacles, trajectory changes and external resistances that force athletes to make rapid, situational adaptations (Young et al., 2015; Petrakos et al., 2016). In this context, resisted-sprint training has

emerged as a particularly effective methodology for developing specific speed and functional muscular power for sporting gestures, since it simulates actual game conditions (Alcaraz et al., 2018; Sannicandro et al., 2024). Exercises such as resisted runs with towing devices, elastic-band sprints or overloaded sprints have been shown to improve neuromuscular, kinetic and kinematic qualities, fostering increases in explosive strength, maximal power and acceleration capacity (Petrakos et al., 2016; Cross et al., 2018). Numerous studies report that systematic use of resisted-sprint protocols leads to optimal performance adaptations—such as enhancements in maximal speed, step frequency and biomechanical efficiency of technical gestures (Rumpf et al., 2016; Cahill et al., 2020). However, the effectiveness of these methods is strongly conditioned by coaching staff’s ability to carefully calibrate load and personalize protocols based on individual athlete characteristics and the specific requirements of the sport (Morin et al., 2017; Altavilla et al., 2023). Despite growing interest in resisted-sprint training, there remains a lack of systematic reviews that critically compare different applications of overload sprinting in team sports—considering parameters such as intensity, duration, equipment and athletes’ individual profiles (D’Elia et al., 2023; Raiola et al. 2019; Esposito et al., 2024). The aim of the present review is to critically examine the common and specific aspects of various resisted-sprint training methodologies applied in team sports, in order to provide practical guidance for optimizing acceleration speed, explosive power and technical effectiveness across different sporting contexts.

Materials and Methods

This study was conducted as a systematic review of the scientific literature, aimed at critically analyzing the common and specific features of resisted-sprint training methodologies in team sports to identify practical recommendations for optimizing physical performance. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework was followed, with inclusion criteria defined a priori (see Table 1). The primary source was the Scopus database, and the search terms used were “resisted sprinting”, “sled training” and “sprint with overload”. Inclusion criteria were: original research articles and systematic reviews; publications in English; relevance to the topic; and full-text availability. During screening, duplicate records, studies lacking empirical data and those not pertinent to the research question were excluded.

Table 1. Inclusion criteria

Web search engines	Scopus
Publishing period	2020-2025
keywords	Resisted sprinting, sled training and sprint with overload
Language	English
Type of article	Original research articles and/or review articles
Full text	Articles matched the purpose and/or topic of the research.

The entire selection process is depicted in the PRISMA flow diagram (Figure 1), which details the number of records identified, screened, excluded, and included in the final review.

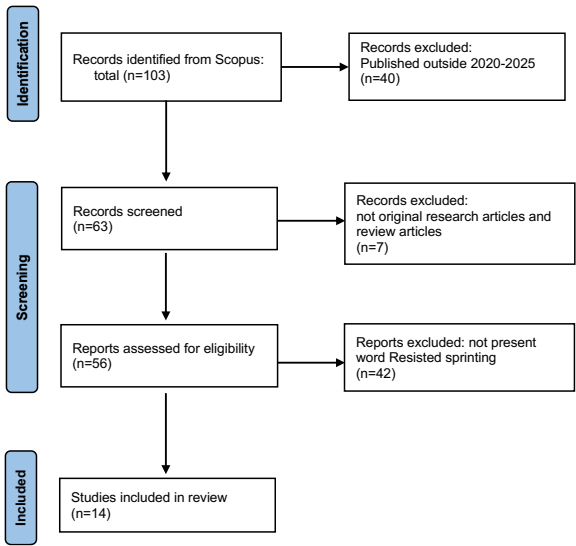


Fig. 1. PRISMA flow diagram illustrating the article selection process.

Results

After conducting the initial search in Scopus, a total of 103 articles were identified. These records were then subjected to additional screening through several phases to yield the 14 studies relevant to our topic. Specifically, 13 experimental studies and 1 systematic review were included. Table 2 summarizes the key characteristics of the included studies, detailing for each: authors, year, topic addressed, methodology employed, and main findings.

Discussion

Optimizing resisted-sprint training requires a clear understanding of in-game demands (Taylor et al., 2017), specifically which actions contribute most to performance and are thus amenable to improvement (Altavilla, 2025). This entails detailed analysis of both training and match loads to obtain quantitative profiles of athletes in team sports such as soccer, basketball, rugby and handball (Bangsbo et al., 2006; Svilar et al., 2018; Parmar et al., 2018; García-Sánchez et al., 2023). Resisted sprints effectively enhance acceleration and neuromuscular power; however, protocol efficacy hinges on precise load determination, the choice of equipment (e.g., Sprint Resister) and meticulous programming (Ceruso et al., 2024). Comparisons between sled towing and weighted-vest sprints reveal similar gains in acceleration, though vest-based loading elicits greater increases in step frequency. Protocols employing sled loads that induce a 50 % velocity decrement or approximately 10–13 % of body mass have demonstrated the greatest effectiveness for improving 5–30 m acceleration, horizontal force production and maximal power (Espasa et al., 2025; Esposito et al., 2024). Profiling instruments, such

Table 2. Results of the literature review

N.	Authors	Topics	Method	Results
1	Stavridis et al., 2023	Heavy sled sprinting, acceleration, kinematics	Original article	Training with sled resistance corresponding to a 50 % velocity decrement (v_{dec}) produced significant improvements in 30 m sprint acceleration, horizontal power and step frequency.
2	Espasa et al., 2025	Resisted sprinting, meta-analysis, team sports	Systematic review	A 6–8-week resisted sprint program using loads of ~10–13 % body mass improved performance over 15–30 m. Loads around 13 % BM for 15–20 m and 12.6 % BM for 10–30 m were effective. Higher loads (40 % BM) yielded benefits, but extreme loads (80 % BM) risked compromising sprint technique.
3	Rakovic et al., 2022	Device validation, sprint profiling, horizontal force	Validation Study / Original Article	The motorized “1080 Sprint” device showed high reliability and validity for 0–30 m sprint timing: coefficient of variation 1–2 %, standard error 0.01–0.05 s, ICC 0.86–0.95—making it an accurate, reproducible tool for monitoring resisted sprint performance.
4	Sugisaki et al., 2025	Force–velocity relationship, resisted sprinting, nonlinear profiling	Original Article	Load dependency in horizontal force–velocity (F–V) sprint profiles is driven chiefly by increased horizontal force at very low speeds during resisted sprints, while differences between profiling methods stem from force reductions near maximal velocity.
5	Zabaloy et al., 2025	Force–velocity profiling, youth rugby, individualized training	Cross-Sectional Study / Original Article	Comparative analysis of sprint F–V variables in youth rugby players revealed significant position-specific differences (forwards vs backs). Component relationships support the use of F–V profiling to design targeted resisted-sprint programs in adolescent athletes.
6	Perez et al., 2022	Ice hockey, sprint profiling, unloaded vs loaded methods	Original article	Unloaded and multi-load sprint profiling produced comparable F–V profiles in female ice hockey players (no significant differences in F_0 , V_0 , P_{max} , V_{opt} or SFV slope). Although correlations were high, loaded methods incurred greater error—suggesting unloaded profiling for general screening and loaded profiling for individualized programming.
7	Cahill et al., 2020	Sled-push training, acceleration, youth athletes	Original article	Sled-push training effectively enhanced horizontal force and initial acceleration in youth athletes without negatively affecting maximal speed—making it a valuable method for developing acceleration-specific neuromuscular adaptations.
8	Zedler et al., 2023	Bobsleigh biomechanics, push phase, acceleration	Original Article (Biomechanical analysis)	Biomechanical analysis of the bobsled push phase showed that initial push force and joint angles significantly influence acceleration. Improving push technique and synchronicity can therefore optimize overall bobsled performance.
9	Skujytė et al., 2024	Sprint timing, validity, reliability	Original article	Smart timing systems for sprint measurement demonstrated excellent reliability (ICC > 0.90) and validity against reference devices. Temporal and velocity parameters were reproducible, supporting their use in youth testing and training programs.
10	Cahill et al., 2021	Sled-pull training, force–velocity, youth performance	Original article	Post-sled-pull F–V profiling continued to show consistent benefits for acceleration and maximal power. Resisted training maintained effective neuromuscular adaptations in youth athletes, indicating potential long-term effects when implemented in repeated intervention cycles.
11	Zisi et al., 2022	Sled vs vest, resisted sprinting, step frequency	Original article	Both sled and vest resisted sprints produced similar accelerative gains, but the vest had a greater effect on step frequency. Both methods are useful for specific training purposes, with the vest offering a more evenly distributed and controllable load.
12	Cochrane et al., 2021	Sprint profiling, resisted sprinting, short-term training	Original article	Short-term resisted training in youth athletes elicited improvements in horizontal force and drove F_0 and P_{max} toward greater adaptations. It allows precise programming, with sled training offering specific acceleration advantages over free sprinting.
13	Uthoff et al., 2020	Sled-push, youth athletes, acceleration	Original article	Sled-push training in youth athletes increased initial acceleration without compromising maximal speed. The force–velocity profile improved, highlighting the importance of these adaptations during sport-specific athletic development phases.
14	Cusano et al., 2025	Sprint resisted, youth football, performance enhancement	Original article	The eight-week use of the Sprint Resister device significantly improved acceleration over 5–10 m and maximal speed over 20–30 m in young soccer players, yielding a mean performance increase of 15 % versus the control group and demonstrating its effectiveness as a resisted-training tool.

as the 1080 Sprint system, have shown high validity and reliability, and force–velocity profiling uncovers load-specific adaptations that support individualized loading strategies based on athlete role, age and sport discipline (Ceruso et al. 2019; D’Elia et al. 2021). The Sprint Resister device, used over eight weeks, significantly enhanced acceleration (5–10 m) and maximal speed (20–30 m) in youth soccer players, while sled-pull interventions consistently improved acceleration and maximal power as evidenced by post-training force–velocity profiles. These findings underscore the importance of matching the training tool to the targeted adaptation. Finally, comparative analyses of sprint force–velocity variables across playing positions reveal significant role-dependent differences, reinforcing the need for personalized training prescriptions.

Methodological Limitations

This review was limited to a single database (Scopus), which may have constrained the comprehensiveness of the literature search. Future reviews should consider additional databases and include elite female athletes to broaden the applicability of the findings.

Practical Implications

Resisted sprint training with loads that induce approximately a 50 % velocity decrement has been shown to be particularly effective for enhancing initial acceleration over 5–30 m (Stavridis et al., 2023; Espasa et al., 2025). Motorized force–velocity profiling systems enable precise individualization of training loads based on F_0 , V_0 and P_{max} parameters, thereby optimizing transfer to sport-specific performance (Rakovic et al., 2022). When selecting between sled towing and weighted-vest protocols, practitioners should align the choice with the primary training objective: sled towing preferentially augments horizontal force production, whereas vest loading increases step frequency without compromising running mechanics (Zisi et al., 2022). It is advisable to implement 1–2 weekly resisted-sprint sessions organized in 4–8-week blocks followed by a taper to consolidate neuromuscular adaptations while preserving free-sprint maximal velocity (Esposito et al. 2019; Morin et al., 2017). In youth athletes, moderate-load protocols safely promote gains in acceleration and explosive power while maintaining technique and minimizing injury risk (Cahill et al., 2020). Continuous monitoring via kinematic and kinetic analyses is essential for assessing program efficacy and for making timely technical corrections that enhance competitive transfer (Cross et al., 2018). Moreover, integrating resisted sprints on slight inclines (3–5°) emphasizes horizontal force production and further improves acceleration under gravitational loading (Cross et al., 2016). Incorporating variable-inertia (flywheel) devices in resisted-sprint drills promotes enhanced eccentric loading, yielding greater muscular-strength increases compared with traditional methods (Norrbrand et al., 2010). The use of wearable monitoring systems to capture velocity, acceleration and joint-angle data allows real-time load adjustments, thereby increasing training effectiveness (Luteberget & Spencer, 2017). Tailoring resisted loads according to each athlete’s individual force–velocity profile, rather than applying fixed

percentages, optimizes neuromuscular adaptations and reduces overload risk (Samozino et al., 2016). Contrast-training sessions that alternate resisted and unresisted sprints exploit post-activation potentiation to boost peak velocity (Turner et al., 2015). Structuring recovery intervals based on physiological or subjective fatigue markers ensures adequate muscle regeneration and prevents performance plateaus (Dupont et al., 2004). Incorporating horizontal plyometric exercises—such as run-up long jumps—reinforces force transmission during the sprint push phase (Spiteri et al., 2013). Finally, a targeted post-training nutrition plan supplying rapidly absorbed proteins and carbohydrates supports neuromuscular recovery and maximizes adaptations to resisted-sprint training (Kerksick et al., 2018).

Conclusions

Resisted sprint training is an effective method for improving acceleration and neuromuscular power. Its success depends on precise load calibration, the deployment of valid profiling instruments and individualized programming tailored to athletes’ roles, ages and sport disciplines. In team sports, decisive actions—such as intercepting opponents and finishing plays—rely on the ability to accelerate quickly and sustain high speeds, often under external resistances and during changes of direction. Resisted-sprint protocols replicate many real-game scenarios, making them well suited both to simulate match conditions and to enhance the neuromuscular qualities specific to competitive sprinting. The critical analysis of common and specific aspects across various resisted-sprint methodologies provides actionable guidelines for optimizing acceleration velocity, explosive power and step frequency in diverse sporting contexts.

Conflict of Interest

The author has no conflict of interest.

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Застосування протоколів зі спринту з опором для покращення прискорення в командних видах спорту: Дані систематичного огляду

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 7 с., 2 табл., 1 рис., 50 джерел.

Історія питання. У командних видах спорту вирішальні дії, як-от прогнозування реалізації схем суперників і досягнення цілей гри, залежать від здатності до швидкого прискорення та підтримання високих показників швидкості, що часто відбувається в умовах зовнішнього опору та під час зміни напрямку руху. Для моделювання цих умов та розвитку специфічних для спринту нервово-м'язових якостей, необхідних у змагальних умовах, запропоновано застосування тренувань зі спринту з опором.

Мета дослідження. Мета цього дослідження полягала в критичному вивченні через систематичний підхід різних методологій спринту з опором (тренування із використанням силових саней, моторизовані системи), що застосовуються в командних видах спорту, задля отримання практичних рекомендацій щодо оптимізації швидкості прискорення та виховної сили.

Матеріали та методи. Відповідно до рекомендацій із пріоритетних елементів звітування для систематичних оглядів та метааналізів (PRISMA) проведено огляд літератури у наукометричній базі даних Scopus (2020–2025) за ключовими словами «спринт з опором», «тренування із використанням силових саней» та «спринт з додатковим навантаженням». Після перегляду 103 записів та аналізу 56 повних текстів статей, залежно від мови, типу статті та релевантності тематиці, було включено 14 досліджень (13 оригінальних наукових статей та 1 метааналіз).

Результати. Згідно з отриманими результатами, встановлено, що застосування протоколів тренувань із використанням силових саней, які відповідають 50 % зниженню швидкості або навантаженням приблизно 10–13 % від маси тіла, сприяло значному поліпшенню показників прискорення на дистанції 5–30 м, створенню горизонтальної сили та максимально вихідної потужності. Інструменти профілювання (наприклад, система 1080 Sprint) довели свою ефективність і надійність, тоді як профілювання сили та швидкості виявило адаптації до конкретних навантажень, що підтримують індивідуалізоване навантаження з урахуванням функції спортсмена, віку та спортивної дисципліни.

Висновки. Результати дослідження свідчать про ефективність тренувань спринту з опором у покращенні прискорення та нервово-м'язової потужності в командних видах спорту. Оптимальні результати залежать від точного калібрування навантаження, використання надійних інструментів профілювання та індивідуальних програм, розроблених з урахуванням конкретних потреб спортсменів та їхніх дисциплін.

Ключові слова: спринт з опором, тренування із використанням силових саней, профілювання сили та швидкості, прискорення, командні види спорту.

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Individualizing Strength Training Using the Vertical Force-Velocity Profile in Vertical Jumping and its Effect on Athletic Performance: A Systematic Review

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Abstract

Background. The individualization of strength training represents a promising strategy for enhancing performance in high-speed actions, such as jumping and sprinting. The vertical force-velocity (F-v) profile allows for the identification of individual imbalances between force and velocity in vertical jumping.

Objectives. This systematic review aimed to analyze the effects of individualized strength training programs based on the vertical F-v profile on jump and sprint performance.

Materials and methods. A comprehensive search was conducted in scientific databases following PRISMA guidelines, analyzing eight studies that met the inclusion criteria. The study involved a total of 353 subjects over 18 years of age participated, including athletes, students, and professional dancers. The training protocols encompassed two weekly sessions over a period of 7 to 12 weeks, using exercises such as squats and vertical jumps, tailored to each individual's F-v profile.

Results. The main results indicated significant improvements in countermovement jump (CMJ), squat jump (SJ), and sprint performance, with greater gains observed in groups that received optimized training based on the F-v profile. The findings were consistent with previous research highlighting the effectiveness of the F-v profile for planning more specific and effective training programs. However, methodological differences were identified among studies, particularly in exercise selection and training volume.

Conclusions. It is concluded that individualized training based on the vertical force-velocity profile is effective in enhancing performance in disciplines requiring explosive actions. This tool allows for optimized strength training programming.

Keywords: force-velocity, individualization, jumping performance, sprinting, strength training.

Introduction

Improving athletic performance requires an individualized approach to training. Each athlete has unique biomechanical, anatomical, and physiological characteristics that affect how they respond to training stimuli (Halsen,

2014). In many sports, actions such as jumping, sprinting, and changing direction are critical (Pleša et al., 2021; Ramirez-Campillo et al., 2020). These movements demand rapid mobilization of body mass or its segments, relying heavily on lower limb (LL) strength.

Neuromuscular capacity of the LL is commonly assessed through jumping tests, which provide relevant, reliable, and specific information (Jiménez-Reyes et al., 2011). However, measuring only jump height may not offer a complete picture of an athlete's performance. Factors such as body

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weight, push-off distance (influenced by leg length), and center of mass height (distance from the ground to the greater trochanter with flexed knees) also play key roles, as highlighted by Samozino et al. (2008). These authors proposed a method based on Newton's laws to estimate force, power, and velocity with greater accuracy.

Subsequent studies using force plates (Jiménez-Reyes et al., 2017a) and linear position transducers (Giroux et al., 2014) have confirmed the validity and reliability of Samozino's method. This led to the development of the vertical force-velocity (F-v) profile (Samozino et al., 2012), a practical and reliable tool for field use. It involves performing five vertical jumps with varying loads to assess the balance between an athlete's ability to produce force, velocity, and power. The data are represented on a Cartesian graph, with force on the Y-axis and velocity on the X-axis. The resulting linear relationship enables theoretical determination of maximum force and velocity.

The slope of the graph indicates the athlete's profile: a steeper slope suggests a force-oriented profile with a velocity deficit, while a flatter slope indicates a velocity-oriented profile with a force deficit. This information is essential for tailoring training programs to the individual needs of each athlete.

Although many LL strength training programs have shown positive effects (Díez et al., 2021), the wide variation in loading methods—such as differences in 1RM percentages or use of bodyweight—raises questions about which approaches are most effective for each athlete. The F-v profile offers a solution by helping identify specific individual deficits in force or velocity production.

Therefore, the objective of this study was to systematically review scientific literature to analyze the effects of training programs individualized according to each athlete's vertical F-v profile, specifically on vertical jumping and sprinting performance. Although the F-v profile was originally designed for vertical movements, previous studies have identified a meaningful relationship between jumping and sprinting (Loturco et al., 2015; Loturco et al., 2017), supporting the relevance of examining its effects on both.

Materials and Methods

Protocol and Registration

This study implemented the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as defined by the EQUATOR Network in 2018, using a pre-established protocol for reviews (Page et al., 2021). The study also optimized basic methodology in the stages of problem formulation, literature search, evaluation, analysis, and presentation of findings to systematize the review process and enhance scientific robustness, following the latest recommendations of the Joanna Briggs Institute (JBI) for scoping reviews (Peters et al., 2020). The aim is to summarize the available literature on the effect of individualized strength training using the vertical force-velocity profile on sprint and jump performance through a mixed analysis of studies. Since this review is not eligible for PROSPERO registration, summarized information and methodology will be made publicly available on Figshare

to avoid unnecessary duplications, with the following DOI: <https://doi.org/10.6084/m9.figshare.25332145>.

Eligibility Criteria

Inclusion criteria for this review include:

- Experimental articles.
- Peer-reviewed articles published between 2010 and 2023.
- Publications written in English.
- Full texts available.
- Articles reporting changes in performance through individualized strength training using the vertical force-velocity profile in sprints and jumps.

Studies that do not correspond to original research (e.g., editorials, notes, dissertations, etc.), that involve populations with underlying pathology, and/or that present methodological limitations will be excluded.

Information Sources

PubMed/MEDLINE, Ebsco and Web of Science were selected for the literature review. Additionally, more articles were manually searched in Google Scholar.

Search Strategy

The search strategy was guided by the PRISMA extension for reporting literature searches in systematic reviews (PRISMA-S) (Rethlefsen et al., 2021). Initially, the PICO framework defined the following question: "Does the Individualization of Strength Training Using the Vertical Force-Velocity Profile Affect Sprint and Jump Performance?"

Table 1. PICO Search Strategy

P	I	C	O
Healthy subjects aged 18 years or older	Clinical studies of 6-8 weeks	Individualized training using the force-velocity profile	Changes in sprint and vertical jump performance

Search algorithms were employed in the selected databases to capture relevant articles for the review. The database searches were conducted during the last week of September 2023. The search algorithms used across all databases included: "force-velocity profile," "velocity-force profile performance," "Force velocity profile AND performance," and "force-velocity profile horizontal performance."

Study Selection and Data Collection Process

Two authors (A.R.J. and S.L.B.) independently searched for articles in the selected databases. Publications meeting the inclusion criteria were selected for further analysis and synthesis phases. A table was designed to report results and compare key findings, including citation/country, study type, study design, participant characteristics, objectives, methodology, results, and conclusions. Discrepancies were identified and re-solved through discussion with a third and fourth author (C.A.G. and D.L.).

Results

After employing search algorithms in the databases (PubMed, Ebsco, and Web of Science), 493 results were obtained. Following an initial filter to eliminate duplicates, 242 potentially eligible articles remained. Evaluating the year, title, and abstracts excluded 225 articles, resulting in 17 studies, of which 10 were excluded due to research design or training programs not meeting criteria. A manual search in Google Scholar found 1 study (Jiménez-Reyes et al., 2019), adding to the 7 studies (Barrera-Domínguez et al., 2023; Escobar Álvarez et al., 2020; Jiménez-Reyes et al., 2017b; Lindberg et al., 2021; Simpson et al., 2021; Zabaloy et al., 2020; Zubčić & Vučetić, 2022) that met all inclusion criteria, resulting in a total of 8 studies. A systematic review was then conducted following PRISMA guidelines, as shown in Figure 1 depicting the literature search flowchart.

Risk of Bias of Included Studies

The risk of bias of included studies was assessed using the modified Cochrane tool RoB-2 for randomized controlled

trials (RCTs) (Sterne et al., 2019). The risk of bias analysis was performed independently by two authors (A.R.J. and S.L.B.), and consensus was reached through discussions with the other two authors (C.A.G. and D.L.). The analysis identified that five of the studies exhibited a moderate risk of bias, while three showed a low risk of bias.

Result Tables

The following tables summarize the characteristics of the studies included in this systematic review, detailing the programs and outcomes observed.

Discussion

This systematic review aimed to analyze the effects of individualized strength training based on the vertical force-velocity (F-v) profile on jumping and sprint performance. The findings support the hypothesis that individualized training interventions based on this profile are more effective than generalized programs, particularly for explosive actions such as the countermovement jump (CMJ), squat jump (SJ), and sprinting.

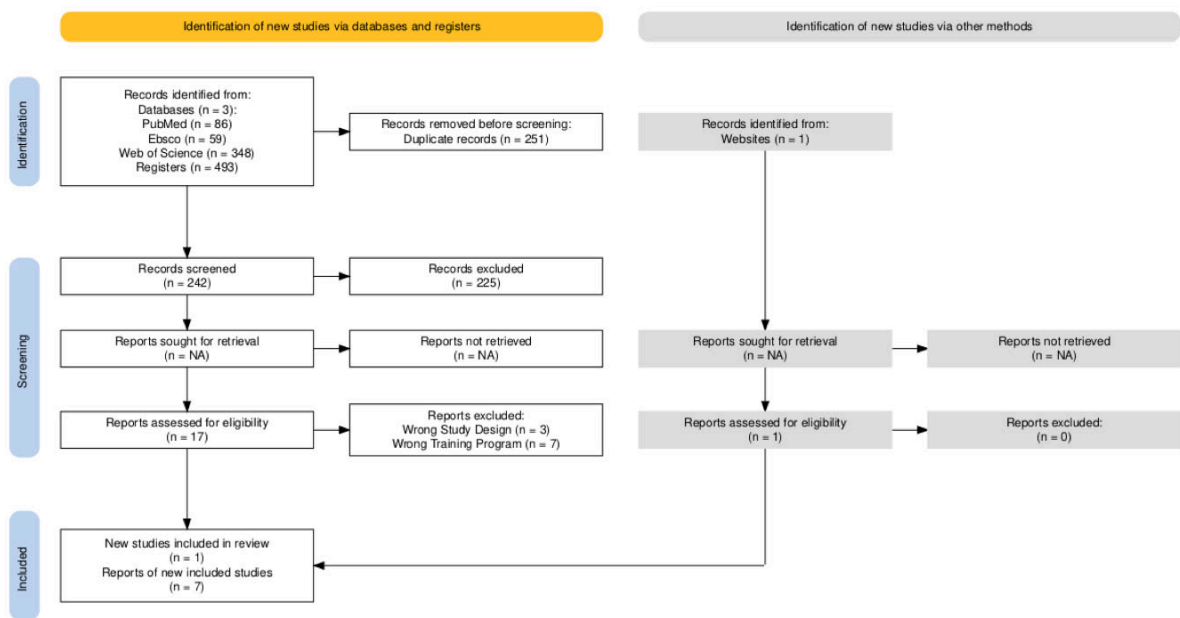


Fig. 1. PRISMA Flow Diagram (Haddaway et al., 2022)

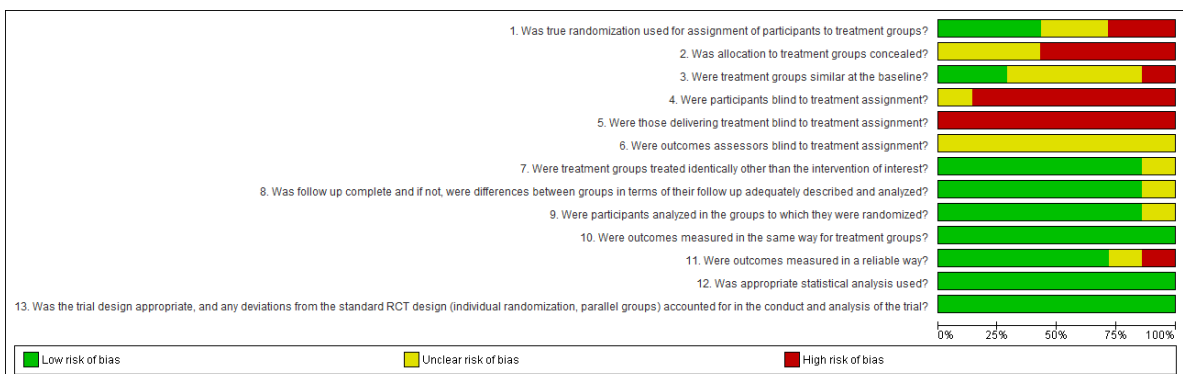


Fig. 2. Risk of Bias Analysis for Selected Studies

Table 2. Summary of Program Characteristics by different studies

Authors	N (M:F)	Age	Exercise (s)	Frequency (days/week)	Intensity (%1RM or VMP m·s ⁻¹)	Volume (sets x reps)	Duration (weeks)	Analyzed Variable	% Change
Barrera-Domínguez et al, 2023.	30 30:0 G _{CON} (n=15) G _{INT} (n=15)	22,9 ± 6,52 years	High Force Deficit Program:	2			8	F0 (N/kg)	G _{CON} : -0,94 G _{INT} : 16,1
			Back Squat		0,68-0,51m·s ⁻¹ 80%-90%1RM	3 sets with 10% VL		V0 (m/s)	G _{CON} : 13,5 G _{INT} : -18,1
			Single leg CMJ		0,71-0,58 m·s ⁻¹	3 sets x 4 reps.		P _{max} (W/kg)	G _{CON} : 10,8 G _{INT} : -1,00
			Deadlift Trap Bar		70%-80%1RM	3 sets with 10% VL		CMJ	G _{CON} : -0,59 G _{INT} : 21,2
			Deadlift Barbell		10%BW	3 sets with 5% VL			G _{CON} : -6,43 G _{INT} : 25,2
			Clean Pull		0.52-0.39 m·s ⁻¹	3 sets x 3 reps.		DjuR	G _{CON} : -3,50 G _{INT} : 24,8
			CMJ Trap Bar		>1,11 m·s ⁻¹ 80% 1RM				G _{CON} : -12,6 G _{INT} : 23,1
			Low Force Deficit Program:		80% BW	3 sets with 10% VL		DJuL	G _{CON} : -14,4 G _{INT} : 19,1
			Back squat			3 sets x 3 reps.			G _{CON} : -2,88 G _{INT} : 6,80
			CMJ trap bar			3 sets x 4 reps.			G _{CON} : -2,78 G _{INT} : 4,63
			Single leg CMJ		0,68-0,51 m·s ⁻¹	3 sets with 10% VL		RSI R	G _{CON} : 0,09 G _{INT} : -5,91
			Deadlift barbell		80%-90%1RM	3 sets with 10% VL			G _{CON} : -1,03 G _{INT} : -7,54
			Clean pull		80%BW	3 sets with 5% VL		RSI L	G _{CON} : -1,57 G _{INT} : -5,64
			Single leg SJ		10%BW	3 sets x 4 reps			G _{CON} : 3,51 G _{INT} : -2,99
			Balanced Program:		0.52-0.39 m·s ⁻¹	3 sets with 10% VL		THT R	G _{CON} : 1,30 G _{INT} : -3,00
			Back squat		85%-95%1RM	3 sets x 5 reps.			G _{CON} : 2,15 G _{INT} : -5,71
			Depth jump		>1.11 m·s ⁻¹ 80%1RM	3 sets x 4 reps.		THT L	G _{CON} : 1,08 G _{INT} : -5,30
			Single leg CMJ		BW	3 sets with 10% VL			G _{CON} : -2,78 G _{INT} : 4,63
			Deadlift trap bar			3 sets x 5 reps.		Sprint (10m)	G _{CON} : 0,09 G _{INT} : -5,91
			Clean pull jump		0,68-0,51 m·s ⁻¹	3 sets x 5 reps.		COD45 R	G _{CON} : -1,03 G _{INT} : -7,54
			Abalakov Jump		80%-90%1RM				G _{CON} : -1,57 G _{INT} : -5,64
			Low Velocity		30cm BW	3 sets x 3 reps.		COD45 L	G _{CON} : 3,51 G _{INT} : -2,99
			Deficit Program:		10%BW	3 sets x 3 reps.			G _{CON} : 1,30 G _{INT} : -3,00
			Depth jump		0,71-0,58 m·s ⁻¹	3 sets x 5 reps.		COD90 R	G _{CON} : 2,15 G _{INT} : -5,71
			Single Leg SJ		70%-80%1RM	3 sets x 3 reps.			G _{CON} : 1,08 G _{INT} : -5,30
			Band Assisted CMJ		65% 1RM	3 sets x 3 reps.		COD90 L	G _{CON} : -2,78 G _{INT} : 4,63
			Clean pull jump		BW	3 sets x 5 reps.			G _{CON} : 0,09 G _{INT} : -5,91
			SJ					COD180 R	G _{CON} : -1,03 G _{INT} : -7,54
			Abalakov Jump			3 sets x 5 reps.		COD180 L	G _{CON} : 2,15 G _{INT} : -5,71
			High Velocity		30cm BW	3 sets x 3 reps.			G _{CON} : 1,08 G _{INT} : -5,30
			Deficit Program:		BW	3 sets x 3 reps.			G _{CON} : -2,78 G _{INT} : 4,63
			Band assisted CMJ		<BW	3 sets x 5 reps.			G _{CON} : 0,09 G _{INT} : -5,91
			Box jump		65% 1RM	3 sets x 3 reps.			G _{CON} : -1,03 G _{INT} : -7,54
			Single leg CMJ		BW	3 sets x 3 reps.			G _{CON} : 2,15 G _{INT} : -5,71
			Abalakov jump		BW				G _{CON} : 1,08 G _{INT} : -5,30
			CMJ						G _{CON} : -2,78 G _{INT} : 4,63
Clean pull jump				G _{CON} : 0,09 G _{INT} : -5,91					
				G _{CON} : -1,03 G _{INT} : -7,54					
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Table 2 (continued)

Authors	N (M:F)	Age	Exercise (s)	Frequency (days/week)	Intensity (%1RM or VMP m·s ⁻¹)	Volume (sets x reps)	Duration (weeks)	Analyzed Variable	% Change
			Box jumps, Stair jumps, Single leg stair jumps, Squat jump w/rubber band, Stair jumps, Trap bar jumps Velocity Program: Half squat, Hip thrust.	1-2 RIR		6 sets por semana x 3 a 8 reps.			G _{BAL} : 5,7 G _{TOW} : 6,7 G _{AW} : 4,2 G _{BAL} : 2,9 G _{TOW} : -9,3 G _{AW} : -7,3 G _{BAL} : 8,4
			Squat jumps, Trapbar jumps, Step up, Squat jump w/rubber band, Countermovement jumps, Box jumps, Clean pull, Stair jumps, Single leg stair jumps.		-50% 1RM	22 sets pos semana x 5 a 10 reps.			
Simpson et al, 2021.	29 29:0 Con (n=14) Int (n=15)	24±3 years	High Force Deficit Program: Squat Box squat Trapbar deadlift Clean pull Squat jump Jump shrug Low Force Deficit Program: Squat Box squat Clean pull Squat jump Jump shrug Squat jump Balanced Program: Squat Clean pull Jump shrug Squat jump CMJ Depth jump Low Velocity Deficit Program: Jump shrug Squat jump CMJ Deph jump Accelerated band jump High Deficit Velocity Program: Jump shrug CMJ Squat jump CMJ Deph jump Accelerated band jump	2	> 80% 1 RM > 80% 1 RM > 80% 1 RM 80, 70, y 65 % 1 RM > 80% > 80% 1 RM 80% 1 RM 70% 1 RM 20-30-65 % 1 RM > 80% 1 RM 80% 1 RM 65% 1 RM 20-30% 1RM 1 RM BW y 10% BW 65% 1 RM 20-30% 1 RM BW <BW-BW 65% 1 RM 10% BW BW BW <BW	3 sets x 3 a 8 reps.	8	SJ Sprint (10m) Sprint (20m) F0 (N/kg) V0 (m/s) SFV% 3 RM Pmax	G _{CON} : 2,33 G _{INT} : 6,98 G _{CON} : -1,74 G _{INT} : -1,75 G _{CON} : -1,26 G _{INT} : -1,27 G _{CON} : -0,09 G _{INT} : 0,81 G _{CON} : 9,39 G _{INT} : 2,90 G _{CON} : -6,35 G _{INT} : -4,80 G _{CON} : -0,09 G _{INT} : 0,81 G _{CON} : 2,86 G _{INT} : 8,57
Escobar Álvarez et al, 2020.	46 0:46 Con (n=10) GINT (n=36) [GLFD n=16 GHFD n=20]	18±9 years	High Force Deficit Program: Leg press Deadlift SJ Back squat	2	90% 1 RM 90% 1 RM 80% BW 80% 1 RM	3 sets x 6 reps. 3 sets x 6 reps. 3 sets x 6 reps. 3 sets x 6 reps.	9	CMJ F0 (N/kg) V0 (m/s) SFV%	G _{CON} : 0,73 G _{INT} : 12,54 G _{CON} : 0,004 G _{INT} : 0,19 G _{CON} : 0,02 G _{INT} : -0,25

Table 2 (continued)

Authors	N (M:F)	Age	Exercise (s)	Frequency (days/week)	Intensity (%1RM or VMP m·s ⁻¹)	Volume (sets x reps)	Duration (weeks)	Analyzed Variable	% Change
Zabaloy et al 2020.	34 34:0 G _{VELOCITY} (n=6) G _{FORCE} (n=11) G _{BALANCED} (n=9) G _{CON} (n=7)	21,5 ± 4 years G _{FORCE} : 23,7 ± 3 years G _{BALANCED} : 22 ± 4 years G _{CON} : 21,4 ± 3 years	CMJ	2	85% BW	3 sets x 6 reps.	7	Pmax	G _{CON} : 0,004
			Single leg CMJ		10%BW	3 sets x 6 reps.			G _{INT} : -0,76
			Low Force Deficit						G _{CON} : 0,04
			Program:			3 sets x 6 reps.			G _{INT} : 0,00
			Leg press		90% 1RM	3 sets x 6 reps.			
			SJ		80% 1RM	3 sets x 6 reps.			
			Single leg CMJ		10% BW	3 sets x 6 reps.			
			Back squat		80% 1RM	3 sets x 6 reps.			
			CMJ		85%BW	3 sets x 6 reps.			
			Single leg SJ		BW				
Jiménez-Reyes et al, 2019.	60 60:0 G _{VELOCITY} (n=24) G _{FORCE} (n=36) G _{BALANCED} (n=6) G _{NON} (n=18) G _{CON} (n=20)	23,1 ± 4 years	Velocity Deficit	2	40%-60% 1RM	2 a 4 sets x 2 a 6 reps.	12,6	F0 (N/kg)	G _{VEL} : -0,16
			Program:		40%-60% BW				G _{FOR} : 0,10
			Squat		BW	2 a 4 sets x 2 a 6 reps.		V0 (m/s)	G _{BAL} : 0,03
			SJ			3 a 6 sets x 10 a 30m			G _{CON} : -0,01
			Sprint		75%-85% 1RM			SFV%	G _{VEL} : 0,17
			Force Deficit		75%-85% BW				G _{FOR} : -0,17
			Program:		BW	2 a 4 sets x 2 a 6 reps.			G _{BAL} : -0,06
			Squat						G _{CON} : 0,01
			SJ		60%-75% 1RM	2 a 4 sets x 2 a 6 reps.		Pmax	G _{VEL} : -0,40
			Sprint		60%-75% BW				G _{FOR} : 0,21
			Balanced Program:		BW	3 a 6 sets x 10 a 30m			G _{BAL} : 0,02
			Squat					CMJ	G _{CON} : 0,00
			SJ			2 a 4 sets x 2 a 6 reps.			G _{VEL} : 0,04
			Sprint			2 a 4 sets x 2 a 6 reps.			G _{FOR} : -0,06
						3 a 6 sets x 10 a 30m		SJ	G _{CON} : -0,004
									G _{VEL} : -0,016
								Sprint (5m)	G _{FOR} : 0,010
									G _{BAL} : 0,02
								Sprint (10m)	G _{CON} : -0,01
									G _{VEL} : 0,05
								Sprint (20m)	G _{FOR} : -0,02
									G _{BAL} : -0,03
								Sprint (30m)	G _{CON} : -0,002
									G _{VEL} : -0,02
									G _{FOR} : -0,01
									G _{BAL} : -0,02
									G _{CON} : -0,02
									G _{VEL} : -0,02
									G _{FOR} : -0,01
									G _{BAL} : -0,03
									G _{CON} : -0,006
									G _{VEL} : -0,01
									G _{FOR} : -0,01
									G _{BAL} : -0,02
									G _{CON} : -0,003
									G _{VEL} : -0,01
									G _{FOR} : -0,01
									G _{BAL} : -0,01
									G _{CON} : -0,007
Jiménez-Reyes et al, 2019.	60 60:0 G _{VELOCITY} (n=24) G _{FORCE} (n=36) G _{BALANCED} (n=6) G _{NON} (n=18) G _{CON} (n=20)	23,1 ± 4 years	Strength	2			12,6	F0 (N/kg)	G _{FOR} : 30,3
			Back squat			3 a 6 sets x 2 a 6 reps		V0 (m/s)	G _{VEL} : -6,77
			Leg press						G _{FOR} : -21,4
			Deadlift					SFV%	G _{VEL} : 15,8
			Strength-power						G _{FOR} : 74,3
			Clean pull					Pmax	G _{VEL} : -19,2
			Deadlift			3 a 6 sets x 2 a 6 reps			G _{FOR} : 0,44
			SJ					SJ	G _{VEL} : 7,79
			CMJ						G _{FOR} : 12,5
			Power			3 a 6 sets x 2 a 6 reps			G _{VEL} : 10,1
Jiménez-Reyes et al, 2019.	60 60:0 G _{VELOCITY} (n=24) G _{FORCE} (n=36) G _{BALANCED} (n=6) G _{NON} (n=18) G _{CON} (n=20)	23,1 ± 4 years	SJ	2			12,6		
			CMJ						
			Single leg SJ						
			Single leg CMJ						
			Clean pull jump			3 a 6 sets x 2 a 6 reps			
			Power-speed						
						3 a 6 sets x 2 a 6 reps			

Table 2 (continued)

[illegible]

Table 2 (continued)

Authors	N (M:F)	Age	Exercise (s)	Frequency (days/week)	Intensity (%1RM or VMP m·s ⁻¹)	Volume (sets x reps)	Duration (weeks)	Analyzed Variable	% Change
			Balanced Program:						
			1 Strength						
			1 Strength-power						
			2 Power						
			1 Power-speed						
			1 Speed						
			Low Velocity						
			Deficit Program:						
			2 Speed						
			2 Power-speed						
			2 Power						
			High Velocity						
			Deficit Program:						
			3 Speed						
			2 Power-speed						
			1 Power						

Note: The following abbreviations and symbols are used throughout Table 2:

Intervention Groups:

GCON = Control group; GINT = Intervention group; GFOR / GFORCE = Force-oriented group; GVEL / GVELOCITY = Velocity-oriented group; GBAL / GBALANCED = Balanced group; GNON = Non-optimized training group; GTOW / GAW = Group Tow / Group Away.

Exercises and Programs:

SJ = Squat Jump; CMJ = Countermovement Jump; DJuR / DJuL = Drop Jump Right / Left; RSI R / L = Reactive Strength Index Right / Left; THT R / L = Triple Hop Test Right / Left; SJ-RFD max = Maximum Rate of Force Development in Squat Jump; Clean Pull = High pull from floor; Jump Shrug = Explosive pull with shoulder shrug; Depth Jump = Jump from elevated platform; Box Jump = Jump onto a box; Band Assisted Jump = Jump with elastic band assistance.

Mechanical Variables:

F₀ (N/kg) = Maximum theoretical force (relative to body mass); V₀ (m/s) = Maximum theoretical velocity; Pmax (W/kg) = Maximum power (relative to body mass); SFV% = Slope of the force-velocity profile; 1RM = One-repetition maximum; BW = Body weight; <BW = Load less than body weight; VL = Velocity loss during exercise; VMP (m·s⁻¹) = Mean propulsive velocity.

Sprint and Change of Direction Tests:

Sprint (5m, 10m, 20m, 30m) = Sprint tests over designated distances; COD45 / COD90 / COD180 = Change of direction at 45°, 90°, and 180°.

Volume and Intensity:

Sets x Reps = Number of sets and repetitions; RIR = Repetitions in reserve.

Across the eight included studies, five reported significant improvements in both CMJ and SJ, and three reported enhancements in sprint performance. These findings align with the theoretical foundation of the F-v profile proposed by Samozino et al. (2012), which emphasizes the importance of tailoring training loads to address individual force or velocity deficits. In studies by Barrera-Domínguez et al. (2023) and Zabaloy et al. (2020), individualized interventions produced greater improvements compared to non-optimized or control groups. This supports the rationale for individualized programming in athletic development.

The predominance of strength deficits in the evaluated populations is notable. This suggests that, in adult athletes—even those engaged in regular sport practice—maximum force output is often a limiting factor in vertical or horizontal explosive performance. It may reflect a broader tendency in sports environments to prioritize technical or tactical training over maximal strength development (Jiménez-Reyes et al., 2017). Consequently, the individualized F-v approach offers a corrective strategy by directing training efforts toward the athlete's specific imbalance.

However, the results were not uniformly positive across all studies or outcome variables. For example, in Barrera-Domínguez et al. (2023), although the program was based on F-v profiling, no improvements were observed in maximum power output (Pmax); yet, the reduction in performance was smaller than in the control group. This may suggest that while the F-v approach minimizes performance decline during intense training periods, it does not guarantee improvement unless programming variables—such as intensity, exercise selection, and progression—are optimized.

Interestingly, some studies (e.g., Simpson et al., 2021) reported partial improvements depending on the deficit group, indicating that the effectiveness of individualized training may vary based on the accuracy of deficit diagnosis or the athletes' baseline characteristics. It is possible that in populations with minimal imbalance or already well-developed strength/power capacities, the marginal gains of optimization are reduced. Conversely, those with more pronounced imbalances may benefit more from individualized plans.

The duration and structure of the interventions also deserve discussion. While all studies included at least two weekly training sessions, the total length ranged from 7 to 12.6 weeks. Shorter interventions may not allow enough time to resolve neuromuscular deficits, particularly in strength-oriented programs. Longer or auto-regulated protocols, such as in Jiménez-Reyes et al. (2019), where training ended when profiles became balanced, may be more effective and athlete-friendly.

Exercise selection varied across studies. Although all included squats and vertical jumps, only one study (Jiménez-Reyes et al., 2019) strictly adhered to the original categorization of exercises proposed by Jiménez-Reyes et al. (2017): strength, strength-power, power, power-speed, and speed. Most deviations involved combining exercise types or modifying set/rep schemes. This raises the question of how much deviation from the original model affects outcomes, and whether hybrid or context-adapted versions of the F-v framework might be equally effective under certain conditions.

Regarding sprint performance, positive outcomes were reported in three of the four studies measuring it. This supports the association between vertical power and horizontal speed described in previous research (Loturco et al., 2015; 2017). However, one study (Jiménez-Reyes et al., 2019) showed improvements that were not superior to the optimized group, suggesting that sprint-specific adaptations may depend on more than vertical F-v training alone, possibly requiring additional horizontal force development or technical sprint work.

In summary, the current evidence confirms that the vertical F-v profile is a useful tool for individualizing training in athletes. While not all interventions led to performance improvements, the general trend supports its application for enhancing vertical and horizontal explosive tasks. Nevertheless, methodological heterogeneity, varying training compliance, and population differences limit the generalizability of the results. Future studies should compare individualized F-v training against other individualized methods and consider combining vertical and horizontal profiling for a more complete picture of athletic needs.

Conclusion

The study concluded that strength training programs optimized according to the vertical F-v profile produced significant and superior improvements in vertical jump and sprint performance compared to non-optimized programs. Individualization of training based on the F-v profile proved to be an effective strategy for enhancing performance in explosive activities such as jumping and sprinting.

Practical Applications

The application of the F-v profile in strength training programs provides a framework for more effective and individualized athlete development. Coaches and trainers can utilize this tool to identify specific deficits in force or velocity and tailor training programs accordingly. This approach not only optimizes performance gains but also minimizes the risk of injury by addressing individual weaknesses. The integration of F-v profiling into regular training assessments can lead to more strategic and informed training decisions, ultimately enhancing athletic performance.

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Індивідуалізація силового тренування із використанням профілю вертикальної сили-швидкості у вертикальному стрибку та його вплив на спортивну результативність: Систематичний огляд

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 11 с., 2 табл., 2 рис., 24 джерела.

Історія питання. Індивідуалізація силових тренувань є перспективною стратегією для підвищення результативності під час виконанні швидкісних дій, як-от стрибки та спринт. Профіль вертикальної сили-швидкості (F-v) дозволяє виявити індивідуальні дисбаланси між силою та швидкістю у вертикальних стрибках.

Мета дослідження. Цей систематичний огляд мав на меті проаналізувати вплив індивідуалізованих програм силових тренувань, розроблених на основі вертикального профілю F-v, на результативність стрибків та спринту.

Матеріали та методи. Проведено комплексний пошук у наукометричних базах даних згідно з рекомендаціями PRISMA, під час якого було проаналізовано вісім досліджень, які відповідали критеріям включення. У дослідженні взяли участь 353 особи віком старше 18 років, включаючи спортсменів, студентів та професійних танцюристів. Протоколи тренувань передбачали проведення двох щотижневих занять протягом періоду від 7 до 12 тижнів із використанням таких вправ, як присідання та вертикальні стрибки, адаптованих до індивідуального профілю F-v кожної особи.

Результати. Основні результати показали значне поліпшення результативності у стрибках з контрпрухом (КРС), стрибках із присіду (ПС) та спринті, причому більші досягнення спостерігалися в групах, які отримували оптимізоване тренування на основі профілю F-v. Отримані дані відповідали результатам попередніх досліджень, які підкреслюють ефективність застосування профілю F-v для планування більш конкретних і дієвих програм тренувань. Однак між дослідженнями встановлено методологічні відмінності, зокрема у виборі вправ та обсязі тренувань.

Висновки. Зроблено висновок про ефективність проведення індивідуалізованого тренування на основі вертикального профілю сили-швидкості щодо підвищення результативності в дисциплінах, що вимагають вибухових дій. Зазначений інструмент дозволяє скласти оптимізовану програму силового тренування.

Ключові слова: сила-швидкість, індивідуалізація, результативність стрибків, спринт, силові тренування.

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Review Article

The Interplay Between Physical Fitness, Nutritional Status, and Academic Performance in Physical Education: A Systematic Review

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Abstract

Objectives. This review aimed to explore the extent to which physical fitness and nutritional status serve as significant predictors of learning outcomes in physical education (PE) among secondary school students. Given the growing concern about sedentary lifestyles and poor eating habits among teens, understanding these relationships is critical to improving physical and academic performance.

Materials and methods. This study used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to screen and analyse the literature related to assessing various relevant studies in the scope of physical education, physical fitness, and nutritional status through a systematic analysis of appropriate literature. Articles published between 2020 and 2025 were examined to determine how to prepare learners to have better physical fitness. A comprehensive search was conducted using the databases Scopus, Web of Science, Google Scholar, and PubMed, with keywords including “physical fitness”, “nutritional status”, “academic achievement”, and “physical education” through a literature review.

Results. This review revealed a strong correlation between physical fitness components (cardiovascular endurance, muscle strength, body composition) and PE learning outcomes. Nutritional adequacy, especially sufficient micronutrient intake and a balanced diet, has also been shown to influence cognitive function, motor skill acquisition, and classroom engagement. However, the interaction between fitness and nutrition appeared to be synergistic and context-dependent.

Conclusions. The findings emphasize that physical fitness and nutritional status are not only important for health but also for successful learning in PE. Schools and policymakers should promote integrated programs that support both areas simultaneously. Further longitudinal and experimental research is needed to confirm the causal pathway. Therefore, strategies are required to improve students' physical fitness and nutritional status to optimize learning and the development of learning outcomes holistically.

Keywords: physical fitness, nutritional status, physical education, learning success, literature review.

Introduction

Physical fitness and nutritional status have an important role in the success of physical education learning. Studies show that good physical fitness and optimal nutritional status can improve concentration, learning endurance, and academic performance of students (Jariono et al., 2025;

Jariono, Nurhidayat, & Indarto, 2024; Jariono, Nurhidayat, Syaokani, et al., 2024). According to (D. Li et al., 2023), there is a positive relationship between physical fitness and academic achievement, especially in subjects that require physical and cognitive activity at the same time such as physical education (Maniaci et al., 2023). In addition, research by Marinković et al., (2024) states that good nutritional status is significantly correlated with the level of student participation and motivation in physical learning. Hansen et al. (2024) Adequate nutrition supports brain

development and cognitive function that are essential in the learning process. Therefore, this study aims to review the relevant literature on the influence of physical fitness and nutritional status on learning success in physical education, highlighting the importance of synergy between physical health and nutritional fulfilment in supporting overall learning quality (Durau et al., 2022).

Physical education is an integral part of the education system that aims to develop the physical, mental, and social aspects of students through structured physical activities (Rosales-Ricardo & Cáceres-Manzano, 2024). In the context of physical education learning, students' academic success and motor skills are highly dependent on a variety of factors, including physical fitness and nutritional status (Liza et al., 2024). Both play an important role in supporting academic performance as well as active participation in physical education learning (Fernandes et al., 2024).

Physical fitness includes various components, such as cardiovascular endurance, muscle strength, flexibility, and body composition (Martín-Rodríguez et al., 2024). Some studies show that a good level of physical fitness is positively associated with improved cognitive function and academic success (Latino & Tafuri, 2024). Studies conducted by Zang et al. (2024) found that children with higher cardiovascular fitness showed better brain activity, especially in tasks that require attention and cognitive control.

In the context of physical education, students who have better physical fitness tend to be more active in participating in learning activities, have higher endurance, and are able to absorb material better than students with low physical fitness (Avraham et al., 2024). In addition, physical activity that improves physical fitness also contributes to the improvement of students' social and emotional skills, which can ultimately support overall learning success (Wilhite et al., 2023).

Nutritional status is an important factor that affects students' health, physical development, and academic performance (Zhou et al., 2024). Good nutrition supports brain development, improves concentration, and improves memory, which is very influential in the learning process (Neuman et al., 2024). Children with poor nutritional status, such as iron deficiency or other micronutrient deficiencies, often experience cognitive impairment and lack of energy to participate in physical and academic activities (Sharma et al., 2023).

Research by Masilela & Modjadji (2023) shows that children with a balanced diet that includes an intake of protein, carbohydrates, healthy fats, vitamins, and minerals have better academic outcomes than those who are malnourished. In addition, adequate nutrition also contributes to the development of physical and motor capacities that support active involvement in physical education (Alamnia et al., 2023).

Several studies have highlighted the relationship between physical fitness, nutritional status, and learning success in physical education. Zhao et al. (2024) It found that aerobic fitness was positively correlated with improved cognitive skills and academic outcomes in elementary school-age children. Muntaner-Mas et al. (2024) states that regular physical activity contributes to improved attention and executive function, which is very important in the learning process. Obeidat et al. (2024) found that students with better

diets had higher academic scores compared to students with poor diets. Mandefro et al. (2024) examined the impact of obesity on academic performance and found that obesity associated with poor diet and lack of physical activity can hinder academic success. Canli et al. (2024) concludes that students with good physical fitness are more likely to have higher motivation and confidence in participating in physical education learning.

Empirical studies are increasingly highlighting the strong link between physical fitness, nutritional status, and academic performance. Cardiorespiratory endurance, muscle strength, and healthy body composition are positively correlated with better cognitive function, attention span, and school engagement (Ingham-Hill et al., 2024). Likewise, adequate nutritional intake especially those involving micronutrients such as iron and omega-3 fatty acids supports brain development and motor coordination (Burnett et al., 2024). However, research examining how these two domains interact in influencing learning outcomes, especially in the context of physical education, remains fragmented.

Given the increasing complexity of adolescent health challenges, there is a need to better understand the interaction between physical fitness and nutritional status as a dual predictor of learning success in physical education. Therefore, this systematic review aims to synthesize the latest empirical findings to (1) analysed the relationship between physical fitness and PE academic performance, (2) examine the effects of nutritional status on PE-related learning, and (3) explore how these two factors together contribute to student outcomes

Materials and Methods

Database and Search Profile

Electronic searches on the Web of Science, Scopus, and PubMed were used to conduct this systematic review. "Physical fitness," "nutritional status," "physical education," and "learning success." through the PRISMA Process which consists of four main stages: identification, screening, eligibility, and inclusion can be elaborated: first stage Identification: A total of 350 articles related to physical fitness, nutritional status, physical education, and learning success, or mixed, were identified from various databases. After removing duplication, as many as 150 articles remain for further screening; The second stage is Screening: Out of 200 articles, 100 articles are filtered by abstract and title. Only 100 articles relevant to the topic; The third stage is Eligibility: Out of 100 articles, 20 articles meet the eligibility criteria after an in-depth evaluation of the methodology and research results; and the fourth stage, namely Inclusion: After a rigorous selection process, as many as 20 articles were included in the final study that met the notability criteria based on the PEDro scale, available for free online (<https://www.pedro.org.au/english/downloads/pedro-scale/>) and have been translated into seven languages in figure 1.

As shown in the flowchart (Figure 1), a total sample of 20 articles was obtained from a total of 350 articles by adhering to the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) (Page et al., 2021) during the identification, screening, suitability, and inclusion phases. The following variables are taken into

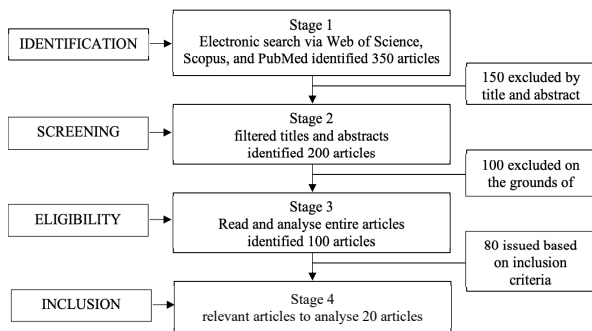


Fig. 1. Diagram of the search process flow

account in the bibliometric analysis: (a) Annual trends of articles published between 2020 and 2025; (b) distribution of publications at the institution of the first author; (c) the number of authors; (d) subject area (physical fitness,” “nutritional status,” “physical education,” and “learning success, or a mixture); (e) type of research (experimental, descriptive, correlational, other); and (f) the average number of citations per article. Further elaborated the inclusion and exclusion criteria are shown in Table 1.

Inclusion criteria, including population, intervention, comparison, outcomes, and study design, are detailed in Table 1. The main focus of the inclusion and exclusion criteria is structured to ensure that only relevant and quality studies are analysed. The study examination includes scientific articles that have gone through a peer-reviewed process, written in English, and published in the period of

2020 to 2025. Studies that are only opinion, editorial, or not available in full-text form are excluded from the review.

The targeted population is school-age children and adolescents (6–18 years old) who are participating in physical education learning in formal institutions. Studies that focused on adults, the elderly, or individuals with clinical conditions that are not relevant to the school’s physical education context were excluded. The selected intervention is a program that aims to improve the physical fitness and/or nutritional status of students, either through the school curriculum, additional sports programs, or nutritional interventions. In contrast, studies that did not include elements of fitness or nutrition in their interventions, or only emphasized the academic aspects without a physical approach, were excluded.

In terms of comparison, studies that include control groups or comparison groups with different treatments are prioritized. Studies without a comparison group or only descriptive in nature were not considered. The results of the study analysed included the effect of interventions on academic performance (such as grades or cognitive ability), physical fitness level (e.g. VO_2 max, muscle strength), and nutritional status (including body mass index or nutrient intake). Studies that did not report such results were not included in the analysis. Finally, the accepted research designs include relevant experimental, quasi-experimental, longitudinal, correlational, and mixed approach quantitative designs. Purely qualitative studies without numerical data linking fitness, nutrition, and academic achievement are not included in the scope of this study.

Table 1. Inclusion criteria and exclusion the interplay between physical fitness, nutritional status, and academic performance in physical education: a systematic review

Component	Inclusion Criteria	Exclusion Criteria
Study Examination	Primary research articles published in accredited scientific journals (peer-reviewed), available in English, and published between 2020–2025.	Non-empirical articles (editorials, opinions, comments), articles are not available in full-text form, or articles in languages other than English and Indonesian.
Population	School-age children and adolescents (6–18 years old) who participate in physical education learning in public schools or other formal educational institutions.	Studies that focus on adult populations, the elderly, or individuals with specific medical conditions that are not relevant to physical education in schools.
Intervention	Programs or activities that aim to improve the physical fitness and/or nutritional status of participants, either based on the physical education curriculum or additional interventions such as extracurricular sports or school nutrition programs.	Interventions that only relate to cognitive aspects without a fitness or nutritional component, or that are not applied in the context of physical education.
Comparison	A control or comparator group that did not receive fitness or nutrition interventions, or that followed a standard physical education curriculum without modification.	Studies that did not have a comparison group or only conducted descriptive observations without comparing different conditions or treatments.
Research Results	The effect of interventions on academic performance (study scores, concentration, learning achievement), physical fitness (VO_2 max, muscle strength, agility), and nutritional status (BMI, nutritional intake, micronutrient deficiencies).	Studies that do not quantitatively or qualitatively measure or report academic outcomes, physical fitness, or nutritional status.
Research Design	Quantitative experimental studies (RCTs, quasi-experimental), longitudinal, correlational studies, or mixed methods that are relevant to the topic.	A purely qualitative study with no numerical data that supports the relationship between fitness, nutrition, and academic performance.

Methodological Quality Assessment

The quality of the articles studied was evaluated using 11 PEDro (Physiotherapy Evidence Database criteria) and have been assessed for methodological quality. Quality articles are essential to assist users in overcoming obstacles such as lack of time and critical thinking skills as well as making it easier to integrate high-quality clinical research into clinical practice. Clinical practice guidelines and systematic reviews are not evaluated Moseley et al. (2020), articles with scores of eight to eleven were rated as having high methodological quality, articles with scores of four to seven as moderate, and articles with scores of four to less (Moseley et al., 2020).

Results

Number of Results Reviewed

On electronic search through the Web of Science, Scopus, and PubMed, through the PRISMA Process. Table 2 below shows the main themes and synthesis results of the publications over the selected time period. Year of publication. These articles include research on the interplay between physical fitness, nutritional status, and academic performance in physical education: a systematic review (table 3).

Recent research shows that physical fitness, particularly the cardiorespiratory component and muscle strength, has a strong relationship with improved cognitive function and academic achievement of students in physical education (PE) subjects. Study by (Zarazaga-pel et al., 2024) and (Brien et al., 2024) revealed that children with good fitness levels showed higher concentration, working memory, and motor coordination abilities, which directly impacted improved learning outcomes.

In addition to physical fitness, nutritional status plays an important role in supporting students' cognitive and physical performance. Research by (O'Connor et al., 2025) and (Moyle, 2025) states that deficiencies in micronutrients

such as iron, iodine, and omega-3s can interfere with brain development and cause decreased memory, fatigue, and difficulty focusing during learning. This has direct implications for student performance in physical and theoretical learning activities at school.

Furthermore, a number of studies suggest that there is a synergistic relationship between physical fitness and nutritional status on educational attainment. The combination of structured physical activity interventions and dietary improvements has been shown to have a dual positive effect on students' cognitive development, learning motivation, and motor skills (D. Li et al., 2023; B. Li et al., 2023). This kind of intervention can be a strategic approach in improving the quality of physical education that is not only oriented to the physical, but also to the overall learning capacity of the students.

However, the strength of the relationship between fitness, nutrition, and learning achievement is also strongly influenced by contextual factors. Factors such as socioeconomic status, sleep quality, family support, and school climate are critical to the success of nutrition and fitness improvement programs (WHO, 2020a) there has been a steady change in trends of delivery patterns worldwide. The overall increase in Caesarean section rates with the decline of vaginal deliveries also raises many growing concerns. Caesarean deliveries have proven to increase the risk of maternal and infant morbidity. 1 Similarly, Organisation for Economic Cooperation and Development (OECD). Therefore, a community-based and comprehensive approach is highly recommended in the implementation of education policies that target students' health and learning outcomes. Table 3 outlines the characteristics of the research studied in the literature review.

Based on a review of various recent studies, it was found that most studies have the same focus, which is to examine the relationship between physical activity, nutritional status, and outcomes such as body composition, physical fitness, cognitive function, and academic achievement.

Tabel 2. Summary of the main literature

Key References (2023–2025)	Main Themes	Synthesis Results
(Fernandes et al., 2024) ; (Canli et al., 2024); PANIC Study (Laamanen et al., 2024)	Physical Fitness and Academic Performance	Cardiovascular fitness (CRF) and muscle fitness have been shown to be positive for executive function, focus, and academic achievement. Cross-sectional tests in adolescents show higher VO ₂ peak correlates with better school scores(Fernandes et al., 2024).
Nutrition & Cognition (Ahmed et al., 2024) & (Elechi et al., 2024) ; Cross-sectional studies (Samigullin et al., 2025); Micronutrient review (2022)	Nutritional Status and Cognitive Function	The intake of macronutrients and micronutrients, especially iron and omega-3, plays a major role in cognitive function, attention, short-term memory, as shown in school-age children.
Stub Meta analysis (Moore et al., 2023); PA+ Review(Janssen & Voelcker-rehage, 2023); Network meta-analysis Exercises (Edwards et al., 2023)	Synergistic Relationships	School-based interventions that mix physical activity and curriculum education simultaneously showed significant improvements in academics, especially mathematics.
EPA obesity study (Smorenburg et al., 2025); PA acute effects review (2024) (James et al., 2023); IoT effect on EF (Peng et al., 2025)	Contextual Factors	The positive effect of physical activity on academics is stronger in obese/at-risk children and depends on frequency, intensity, duration (FITT). Abdominal obesity is associated with changes in the hippocampus and amygdala that can interfere with learning function.

Tabel 3. Characteristics of the research examined in the literature review

Author and Year	Population and Sample	Data Collection Techniques	Synthesis Results
(Bernard et al., 2025)	25 community intervention studies involved elderly adults with low incomes and/or living in rural areas. Of the 2,954 initial citations, 25 articles met the inclusion criteria; Only 2 studies involved rural populations specifically.	Systematic search on 4 databases through July 2024, using Arksey & O'Malley's scoping methodology; classification of intervention types based on the Michie Behaviour Change Wheel	All interventions showed positive outcomes: increased fruit & vegetable consumption, physical activity levels, functional fitness, and nutritional knowledge. There is a shortage of studies specific to rural populations, only two indicating the need to expand research in rural contexts.
(Cabral et al., 2025)	41 studies in children totalling 7 316 participants; include acute and chronic interventions.	Meta-analysis of studies related to cognitive and/or aerobic physical activity, comparing with sedentary controls, regular aerobic exercise, or PJK classes; Calculate the pre-post and post-test effects.	Acute (short activity): Small to large effects in pre-post, significant only on working memory accuracy when compared to rest.
(Ferozi et al., 2024)	100 youth ages 12–15 in Delhi (India)	Lifestyle questionnaire; height, weight, BMI, body fat%; battery FITNESSGRAM, * PAQ-A; 2x24-hour meal recall	19 % overweight, 6 % obese; 74% are physically passive; negative correlation of physical activity vs multiple nutritional indices; positive grip strength with BMI; Low nutrition & fitness need intervention.
(Pinto-Escalona et al., 2024)	Children aged 7–8 years (grade 2 of primary school) from 20 schools in 5 European countries; a total of 721 children (344 females, 377 males); 388 intervened and 333 controls	Academic: The average grade point average of the semester (scale of 010) is determined by the teacher and standardized by country; Psychosocial: Strengths and Difficulties Questionnaire (SDQ) version of parents; and Physical fitness: shuttle run test (aerobics), Y Balance Test (balance), frontal split test (flexibility)	A one-year school-based karate program is effective: improving academic achievement, physical fitness (aerobics & balance), and reducing conduct problems in 7–8-year-olds. These findings support the integration of karate in the PJ curriculum to improve students' physical and cognitive outcomes
(Zang et al., 2024b)	2,655 healthy children (women & boys), 1,308 in the intervention group and 1,347 in the control group	Literature search from 10 databases (e.g. PubMed, Scopus, CNKI) to November 2023 8 RCTs were selected based on inclusion criteria (healthy children, AE >50 weeks for academics); Tools: Cochrane RoB2 for bias, funnel plot & Egger's test for publication bias, combined effects analysis via R (fixed/random model)	Inhibitory control was significantly improved in the aerobic group (SMD = 0.29; 95% CI [0.05, 0.54]; p = 0.018); increased working memory (SMD = 0.25; 95 % CI [0.07, 0.42]; p = 0.005); Increased cognitive flexibility (SMD = 0.36; 95 % CI [0.17, 0.54]; p < 0.001); Academic achievement only significantly improved if the aerobic duration > 50 weeks (SMD = 1.19; 95% CI [0.34, 2.04]; p = 0.006) Publication bias was not significant (p > 0.1) and the quality of the evidence was low.
(Vaquero-sol et al., 2024)	1166 junior high school students in Extremadura, Spain; 642 males (mean age 13.16 ± 0.91 years) and 524 females (13.08 ± 0.85 years)	Physical activity: PAQA (Physical Activity Questionnaire for Adolescents)- Body composition: measurement of weight and height → BMI- Cardiovascular fitness: CourseNavette test- Body dissatisfaction: a scale of body dissatisfaction (expressed in the Study, although the details of the instrument are not mentioned)	Increased physical activity was significantly correlated with improvements in BMI, cardiopulmonary fitness, and reduced body dissatisfaction, especially in male students. Interventions in PJK subjects are very important to promote a healthy lifestyle and support adolescents' physical health and body image.

Table 3 (continued)

Author and Year	Population and Sample	Data Collection Techniques	Synthesis Results
(Pelc et al., 2024)	55 active individuals aged 16–61 years; 28 people with disabilities (Frame Running) and 27 nondisabilities, adjusted by age, gender, and physical activity level	FFQ6 (food frequency questionnaire)- Bioimpedance analyser (Tanita) for body composition (fat, muscle, bone mass)- Stadiometer for height	Subjects with active disabilities had a different body composition and higher body fat, but consumption of vegetables and animal fats was dominant. Diet has a significant effect on body composition, so balanced nutritional interventions and a healthy lifestyle are recommended, especially for people with disabilities
(Mateo-orcajada & Vaquero-crist, 2024)	Adolescents aged 12–16 years; the review included 12 systematic reviews (273 articles total), with 22 intervention studies using mobile apps exclusively in this age group. In separate RCTs: active versus inactive adolescents; sample details were not mentioned.	- Search of literature on Web of Science, PubMed, Scopus, Google Scholar. - Selection of reviews based on criteria (age, duration of ≥ 8 weeks, pre-post measurement). - Quality assessment with external AMSTAR2 and validity analysis. On RCTs: measurements of kinaanthropometry, body composition, and fitness.	Mobile apps alone have not been effective in increasing physical activity or body/fitness variables in adolescents 12–16 years old. It is emphasized that subsequent interventions need stronger designs, larger samples, and more solid methods to produce more convincing evidence
(Shao & Zhou, 2023)	Youth aged 10–19 years, various countries; Total primary studies filtered from 5 databases as of August 14, 2022	Literature exploration on EBSCOhost (ERIC), Psychology & Behavioural Science Collection, PubMed, Scopus, Web of Science; Selection of studies on physical, cognitive, social & lifestyle factors	Adolescents' physical activity habits are influenced by many biological, psychological, environmental, and lifestyle dimensions that should be targeted by comprehensive interventions
(Wu et al., 2023)	3,258 13-year-olds from the general population cohort Generation R in Rotterdam, Netherlands	Self-report questionnaire for daily physical activity and screen time; Body composition measurement: BMI, DXA (fat mass & lean body mass), MRI (subcutaneous & visceral fat)	Higher physical activity and lower screen time were seen as effective in lowering general and visceral adiposity in adolescents.
(Eglseer et al., 2023)	4,957 participants (aged 55–70 years, overweight/obese) from 66 RCTs with a total inclusion of 92 main studies for review	Systematic collection of data from four databases up to July 2022; RCT analysis with network meta-analysis, random effects, pooled mean differences, SMD, CI 95%, subgroup & sensitivity analysis	a combination of a low-energy, exercise and high-protein diet is the optimal intervention to improve the body composition of adults approaching retirement; Diet alone can lead to sarcopenic obesity.
(Jylänki et al., 2022)	2,472 children aged 3–7 years from 35 primary studies (7 databases as of April 2020)	A systematic review of 35 studies in children aged 3–7 years ($n = 2,472$), using PRISMA methodological standards and EPHPP assessments.	Interventions that combine fundamental motor skills and physical activity significantly improve cognitive and academic abilities, especially memory, executive, language, and numeracy. A combination of skill practice is more effective than general physical activity; The motor skill approach is better than activity alone.
(Zukowska et al., 2022)	The study covers the general population, not limited to specific age groups or demographics	The literature review used six databases, resulting in 17 studies that were analysed with classification and quality assessment.	A comprehensive transportation policy combines the most effective physical, educational, and public support elements in encouraging the physical activities of the wider community.

Table 3 (continued)

Author and Year	Population and Sample	Data Collection Techniques	Synthesis Results
(Bogataj et al., 2021)	48 adolescent girls were overweight (mean age = 15.6 ± 0.7 years); divided: 24 in the intervention group (EXP) and 24 in the control group (CON)	Body composition through measurements of body fat, BMI, and body fat Physical fitness: countermovement jump (CMJ), medicine ball throw, hand-grip strength, and Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1 HIIT intervention for 8 weeks (3×/week), as well as nutrition education sessions 2×/week	Significant interactions (group × time) for body weight ($p = 0.008$), BMI ($p = 0.020$), body fat kg ($p < 0.001$), and body fat % ($p < 0.001$) Significant improvements in medicine ball throw ($p < 0.001$) and YYIRT1 ($p = 0.024$) Significant time effects for hand-grip ($p = 0.004$) and CMJ ($p = 0.001$) Conclusions: An 8-week school-based HIIT program, plus nutritional interventions, Effective in improving body composition and muscle and aerobic fitness in overweight adolescent girls
(Wang & Boros, 2021)	Healthy general population, literature review from Jan 2010–Jun 2018, total of 14 quantitative studies	Systematic search of PubMed & Scopus; A selection of studies that compared the intensity of physical activity (light, moderate, severe) to sleep quality	Moderate-intensity physical activity is more effective in improving sleep quality than strenuous activity. These findings are consistent across different age groups
(Ruhland & Lange, 2021)	School-age children (7–16 years), a total of 6,032 students from 20 studies	Prospective reviews (RCTs and non-RCTs) using large databases according to PRISMA; Study Quality Assessment with Standard Checklist	Generally, active breaks in the classroom (light to moderate mobility) increase focus and task time. Measurements were carried out through d2 tests, TEACH, and behavioural observations
(Farooq et al., 2020)	52 longitudinal studies, totalling 22,091 children and adolescents aged 3–18 years (8,857 boys, 13,234 girls) from different countries	Physical activity measurement using an accelerometer (MVPA in minutes per day) was followed for at least 1 year. Search through December 2018 in 10 databases	MVPA decreases significantly with age, faster in women, with a critical period in the transition period from primary to secondary school. Designing interventions targeting 9–12-year-olds, particularly women, is critical.
(Haverkamp et al., 2020)	Healthy adolescents & young adults aged 12–30 years; acute intervention: $n = 44$ studies; Chronic: $n = 27$	Systematic searches on Embase, ERIC, MEDLINE, PsycINFO, Web of Science. Only controlled studies (controls/experiments)	Physical activity interventions, both brief (acute) and sustained (chronic), significantly improve various aspects of cognitive function (processing speed, attention, inhibitory control, working memory, cognitive flexibility) and language skills in adolescents and young adults
(Sember et al., 2020)	The study included 44 experimental interventions (>6 weeks) in children/adolescents aged 6–19 years in a school setting	Randomized meta-analysis with validity generalization; Grouping of subgroups based on the qualifications of the program implementer	Positive effects on academic/cognitive ($r = 0.181$), Interventions guided by competent personnel produced greater effects ($r = 0.22$), and Many studies did not report activity intensity, which was a critical factor.
(Gelius et al., 2020)	A review of 57 reviews covering 53 types of policies promoting physical activity, a variety of settings (schools, transport, environment), without a direct human population	The review-review study, filtering 57 primary sources related to physical activity promotion policies, was systematically analysed using the EPPI-Reviewer tool	Policies in the context of schools (more and more quality physical education lessons) and public infrastructure policies (green spaces, walking/cycling paths) have proven effective. Fiscal policy (subsidies, taxes) still needs stronger evidence

The majority of studies used a quantitative approach, with longitudinal, experimental, and meta-analysis designs, and involved children and adolescents as the main population. Almost all interventions, whether physical, nutritional, or a combination of both, showed positive results on participants' physical and cognitive health. Nevertheless, there were striking differences in duration, intervention methods, and output focus. Some studies emphasize on improving brain function (such as memory and cognitive control), while others focus on improving body composition, self-image, or behavioural changes. In addition, most research was conducted in school and urban settings, with few studies specifically targeting rural communities or older groups. Therefore, it is recommended that future interventions be multimodal, adaptive to local contexts, and include more diverse populations, especially vulnerable groups in rural areas as well as non-productive ages.

Discussion

The results of this study reveal that physical fitness and nutritional status play an important role in supporting students' academic achievement, especially in physical education. The balance between physical condition and optimal nutritional intake has been proven to be able to increase concentration, motivation, and learning outcomes. These findings confirm the need for a holistic approach in education, which includes aspects of physical health and nutrition as support for academic success.

Furthermore, physical fitness and nutritional status have a very important role in supporting learning success, especially in the context of physical education. Physical fitness and nutritional status play a very important role in supporting learning success, especially in the context of physical education. Physical fitness reflects a person's physical capacity to perform daily activities efficiently without experiencing excessive fatigue and still having energy reserves for other activities (Redondo-Flórez et al., 2022). Meanwhile, a good nutritional status contributes to optimal cognitive development, endurance, and motor skills for students (WHO, 2020b). Studies have shown that students with good physical fitness and balanced nutritional status tend to have higher academic performance compared to students who are deficient in both aspects (García-Hermoso et al., 2021).

In physical education, physical fitness is a key factor that affects student involvement in physical activity. According to research conducted by Ma et al. (2020), students with higher levels of physical fitness show better motor skills, more active participation in physical activities, and have better endurance in taking lessons. Good physical fitness is also associated with more stable mental health, so students tend to have lower stress levels as well as higher motivation to learn (Jariono, Nurhidayat, & Indarto, 2024). Therefore, students who have optimal physical fitness are better able to absorb learning materials well and have superior academic performance.

On the other hand, nutritional status is also an important predictor of learning success. Adequate and balanced nutrition affects brain development, memory, and focus on learning. Research conducted by Taras (2005) suggests that students with nutritional deficiencies, such as

iron deficiency or certain vitamin deficiencies, tend to have difficulty concentrating and have lower problem-solving abilities. In addition, a study by Edimo Dikobo et al. (2023) found that students who were malnourished tended to have lower attendance rates in school, which directly impacted their academic achievement.

Further, the relationship between physical fitness, nutritional status, and academic performance has been extensively researched. A longitudinal study by Hermassi et al. (2021) in the United States found that students with higher levels of physical fitness performed better in subjects such as math and language compared to students with lower levels of physical fitness. In addition, research by Alvarez-Bueno et al. (2017) has also shown that regular physical activity can improve cognitive function and academic achievement, especially in terms of working memory and information processing speed.

In the context of physical education, teachers have an important role to play in ensuring that students get the optimal benefits from the physical activities carried out in school. An effective physical education program not only aims to improve physical fitness but also educates students about the importance of good nutrition to support their health and academic achievement. A study by Yasin Akinci & Sadettin Kirazci (2022) emphasizes that schools need to integrate a physical activity-based approach with nutrition education to create a healthier learning environment and support better academic achievement.

To improve the physical fitness and nutritional status of students, several recommendations can be implemented in the education system. First, schools need to provide adequate sports facilities as well as attractive and varied physical education programs to increase student participation in physical activities. Second, schools need to pay attention to the availability of healthy food in the canteen and provide nutrition education regularly to students so that they understand the importance of a balanced diet. Third, parental involvement in supporting their children's healthy eating and physical activity habits is also an important factor in ensuring the success of this strategy.

Physical Fitness and Nutritional Status as Predictors of Learning Success in Physical Education: Physical fitness and nutritional status play crucial roles in determining students' academic performance, particularly in physical education. Numerous studies have demonstrated that students with higher physical fitness levels tend to perform better academically due to improved cognitive functions, concentration, and overall well-being (Álvarez-Bueno et al., 2017). Similarly, proper nutritional intake is essential for cognitive development and learning efficiency, as it directly impacts energy levels, memory, and motivation (Burrows et al., 2017). This discussion explores the relationship between physical fitness, nutritional status, and learning success in physical education, supported by previous research findings.

Physical Fitness and Academic Performance in Physical Education: Physical fitness encompasses various components such as cardiovascular endurance, muscular strength, flexibility, and body composition, all of which contribute to overall health and functional capabilities (Raul Roscamp de Oliveira et al., 2023). A well-rounded fitness level allows students to actively participate in physical education classes, enhancing their skill acquisition, motor coordination,

and overall engagement in learning activities. Research by (Chaddock-Heyman et al., 2014) found that students with higher aerobic fitness exhibited better executive function and cognitive flexibility, which are essential for both academic and physical performance.

Moreover, physical activity has been linked to improved brain function through increased blood flow and neurogenesis, fostering better memory retention and learning efficiency (Donnelly et al., 2016). In the context of physical education, students who regularly engage in exercise demonstrate better skill development, higher motivation, and increased confidence in physical tasks, all of which contribute to their learning success (Gerber et al., 2025). A study by (Haapala et al., 2014) emphasized that students with better motor skills and physical endurance were more likely to excel in physical education assessments, indicating a strong correlation between fitness and learning outcomes.

Nutritional Status and Learning Success: Nutrition plays an equally significant role in academic achievement, as it directly influences cognitive function and physical performance. Proper nutrition ensures adequate energy levels for participation in physical activities and supports muscle recovery and growth. Deficiencies in essential nutrients such as iron, vitamin B12, and omega-3 fatty acids have been linked to decreased cognitive function, reduced attention span, and lower academic performance (Nyaradi et al., 2013).

A study conducted by Florence et al. (2008) found that students who consumed a balanced diet, including sufficient fruits, vegetables, and protein, performed better in physical education and general academic subjects. Similarly, Burrows et al. (2017) noted that malnutrition, whether undernutrition or overnutrition (obesity), negatively affected students' ability to focus, participate in physical activities, and engage in learning. Overweight students often experience reduced physical capacity, lower self-esteem, and decreased motivation to participate in sports and physical education tasks, further hindering their learning success.

Additionally, proper hydration and meal timing significantly impact students' physical performance. Research by Guzek et al. (2022) indicated that students who had a nutritious breakfast demonstrated better endurance and focus in physical education classes compared to those who skipped meals. This aligns with findings by Adolphus et al. (2013), which suggests that a well-balanced diet enhances memory, attention, and learning efficiency, further reinforcing the importance of nutrition in education.

The Combined Impact of Physical Fitness and Nutrition on Learning Outcomes: Both physical fitness and proper nutrition contribute synergistically to academic success, particularly in subjects like physical education that demand active participation and motor skill development. Students who maintain a physically active lifestyle and consume a nutritious diet are more likely to develop resilience, discipline, and a positive attitude toward learning (Tomprowski et al., 2011). A longitudinal study by Esteban-Cornejo et al. (2017) found that students with a combination of high fitness levels and good nutritional status performed significantly better in physical education and other subjects compared to those who lacked either component. This supports the argument that an integrated approach, combining structured physical education programs with proper nutritional guidance, is essential for maximizing student learning outcomes.

Implications for Education Policy and Practice: Given the substantial impact of physical fitness and nutrition on learning success, schools should prioritize comprehensive programs that promote active lifestyles and healthy eating habits. Implementing structured physical education curricula that emphasize cardiovascular endurance, strength training, and flexibility exercises can enhance students' overall fitness levels. Additionally, integrating nutritional education into school programs can help students make informed dietary choices, leading to better academic performance (Story et al., 2009). Teachers and school administrators should also collaborate with parents to ensure students receive adequate physical activity and nutrition outside of school. Encouraging participation in extracurricular sports, providing healthy meal options in school cafeterias, and conducting regular health assessments can further support students' academic and physical well-being.

Overall, physical fitness and nutritional status are closely related to learning success in physical education and other academic fields. Previous research has shown that good physical fitness can improve students' motor skills, learning motivation, and mental health, while optimal nutritional status contributes to better cognitive development and endurance. Therefore, the integration of physical fitness and nutrition education in the educational curriculum is a must to support the development of students as a whole, both from a physical and academic perspective.

Conclusions

Based on the literature review, it can be concluded that physical fitness and nutritional status are significant predictors of learning success in physical education. Students who have good physical fitness and optimal nutritional status tend to have better academic performance and superior motor skills. Therefore, an intervention approach that includes improving physical fitness through structured physical activity and dietary improvement is needed to support a more effective learning process in a physical education environment.

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Conflict of interest

The research has no conflict of interest, and the entire process is conducted independently without external intervention.

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Взаємозв'язок між фізичною підготовленістю, нутритивним статусом та академічною успішністю у фізичному вихованні: Систематичний огляд

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 14 с., 3 табл., 1 рис., 70 джерел.

Мета дослідження. Цей огляд мав на меті дослідити, наскільки фізична підготовленість та нутритивний статус є значущими предикторами результатів навчальної діяльності у фізичному вихованні (ФВ) серед учнів середніх шкіл. Враховуючи зростаючу стурбованість щодо малорухливого способу життя та нездорових харчових звичок серед підлітків, розуміння цих взаємозв'язків є критично важливим для поліпшення фізичної та академічної результативності.

Матеріали та методи. У цьому дослідженні використовувався метод пріоритетних елементів звітування для систематичних оглядів та метааналізів (PRISMA) з метою відбору та аналізу літератури, пов'язаної з оцінкою різних релевантних досліджень у галузі фізичного виховання, фізичної підготовленості та нутритивного статусу, що було здійснено шляхом систематичного аналізу відповідної літератури. Для визначення способів підготовки учнів щодо покращення їх фізичної підготовленості було проаналізовано статті, опубліковані у період з 2020 по 2025 рік. За допомогою літературного огляду проведено комплексний пошук із використанням наукометричних баз даних Scopus, Web of Science, Google Scholar та PubMed за наступними ключовими словами: «фізична підготовленість», «нутритивний статус», «академічні досягнення» та «фізичне виховання».

Результати. Представлений огляд встановив сильну кореляцію між складовими фізичної підготовленості (серцево-судинна витривалість, м'язова сила, композиція тіла) та результатами навчання з фізичного виховання. Також було доведено, що повноцінність харчування, особливо достатнє споживання мікроелементів та збалансована дієта, впливає на когнітивні функції, набуття моторних навичок та залученість учнів до навчального процесу. Однак взаємодія між фізичною підготовленістю та харчуванням виявилася синергічною та залежала від контексту.

Висновки. Результати дослідження підкреслюють, що фізична підготовленість та нутритивний статус є важливими не тільки для здоров'я, але й для успішного навчання на уроках фізичного виховання. Школи та політичні діячі мають сприяти впровадженню інтегрованих програм, що передбачають одночасну підтримку обох зазначених галузей. З метою підтвердження причинно-наслідкового зв'язку необхідно провести додаткові лонгітюдні та експериментальні дослідження. Отже, задля комплексної оптимізації навчання та розвитку результативності навчальної діяльності потребуються стратегії, спрямовані на поліпшення фізичної підготовленості та нутритивного статусу учнів.

Ключові слова: фізична підготовленість, нутритивний статус, фізичне виховання, успішність у навчанні, огляд літератури.

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