

НАУКОВО-МЕТОДИЧНИЙ ЖУРНАЛ



# ТЕОРІЯ ТА МЕТОДИКА ФІЗИЧНОГО ВИХОВАННЯ

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[Teorià ta Metodika Fìzičnogò Vihovannâ]



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## THE DIFFERENTIAL EFFECTS OF UPHILL SPRINT AND SIDE JUMP SPRINT EXERCISES AND VARIOUS ANTHROPOMETRIC CHARACTERISTICS ON THE SPEED OF SOCCER PLAYERS

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### Abstract

**Study purpose.** To increase the running speed of soccer players, anthropometric factors need to be considered when choosing a training model.

**Materials and methods.** The experimental method with a 2×3 factorial design was used in this study. Purpose random sampling technique was used to select a sample of 60 participants from a population of 100 people. Then the sample was divided into six groups using a stratified random sampling technique (large UHS, n = 10 participants; moderate UHS, n = 10 participants; small UHS, n = 10 participants; large SJS, n = 10 participants; moderate SJS, n = 10 participants; small SJS, n = 10 participants). The 20-meter running speed test and anthropometric measurements were used as data collection instruments. Data analysis uses a two-way ANOVA and normality and homogeneity tests as prerequisites.

**Results.** The results of the study found that there were significant differences in the two training models with a Sig value of  $0.002 < 0.05$ , there were significant differences in the three anthropometric groups with a Sig value of  $0.000 < 0.05$ , and there was an interaction between the training model and anthropometric characteristics in increasing the 20-meter running speed with a Sig value of  $0.001 < 0.05$ .

**Conclusions.** This study concluded that the SJS training model was suitable for three levels of anthropometric ratios, while UHS was very suitable for small ones. Another conclusion was that the small anthropometric ratio had the greatest effect on the speed of the 20-meter sprint.

**Keywords:** uphill sprint, side jump sprint, anthropometry, 20-meter running speed, soccer.

### Introduction

Running speed in a soccer game can be an added advantage for teams and individuals. In identifying the talent of elite young soccer players, the ability to run fast and sprint is very important (Murtagh et al., 2018). Running speed can be used in match situations such as attacking, defending, and transitions (Izquierdo et al., 2023; Owen, 2022; Power, 2020). When attacking running speed, an

attacker is needed to penetrate with the ball or without the ball; when defending running speed, a defender is needed to intercept the ball; when transitioning, running speed is needed when counterattacking or anticipating counterattacks (Modric et al., 2023). Running speed is also needed when playing possession ball (Gong et al., 2021; Yi et al., 2019). Running speed is positively related to the ability to score goals in soccer players (Faude et al., 2012; Martínez-Hernández et al., 2023; Wilson et al., 2020). To evaluate the playing level of soccer players, running speed is one of the parameters used (Devismes et al., 2021). In 2018 Gonçalves et al. (2018) findings show that the speed and synchronization of the speed of soccer players tend

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to decrease in the second half of the match. However, the variation of speed synchronization between matches tends to increase. Therefore, soccer players must develop their running ability, especially within 20 meters, to optimize their running speed in various game situations, contributing to team success and individual achievements (Nicholson et al., 2022). According to the opinions of Rey et al. (2024) suggests that short-distance running exercises can improve sprint performance and turning speed. In addition, to evaluate players' physical abilities, a running speed of 20 meters is one of the parameters used (Altmann et al., 2019).

Another factor that affects the running speed of a soccer player is anthropometry. In the sports context, anthropometry is used to measure and analyze players' physical characteristics, such as height, weight, arm length, shoulder width, and body composition (Preedy, 2012). Each player has different anthropometric characteristics for both men and women (Pedersen et al., 2019). Differences in playing positions and ages of soccer players are also related to anthropometric characteristics (Taketomi et al., 2021). Anthropometric data can assist in determining training needs, designing appropriate training programs, and understanding how these physical factors can affect athlete performance in various sports. Especially the ratio of sitting height and standing height, plays an important role in the running speed of soccer players (Leão et al., 2019). This ratio refers to the ratio between sitting height (body length when sitting) and standing height (body length when standing upright). The ratio of sitting height and standing height can give an idea of the proportions of a player's body, especially the length of the legs relative to the overall body length. Players with small ratios tend to have longer legs compared to their height. Mechanical advantage will be obtained by players who have this ratio. More speed and distance will be obtained for players with longer leg reach (Parpa & Michaelides, 2022). In addition, stability and balance in the running are also influenced by anthropometric ratios. Balanced body proportions help players maintain good posture and balance when moving quickly. Understanding anthropometry, especially the ratio of sitting height and standing height, is important in selecting soccer players and developing appropriate training programs (Rebelo et al., 2013). Therefore, to increase the running speed of soccer players, it is important to pay attention to this anthropometric factor and use it as a guide in evaluating and developing players (Bordonau & Villanueva, 2012). Although running speed is an important aspect of soccer, gap analysis shows that training and research methods that specifically lead to an increase in sprint speed, taking into account the anthropometric factors of soccer players, still need to be completed (Bulqini et al., 2016). The need for optimal running speed in soccer is very important, given the dynamic nature of the game, and it often involves situations where players must pass opponents quickly. However, in many studies and exercise programs, the focus tends to be more on other physical aspects (Clemente et al., 2023).

The implementation of speed training has found its application across various domains. Plyometric training and sprinting at maximum speed are commonly employed techniques to enhance the power generation of elite soccer players rapidly and with optimal efficiency (Loturco et al., 2022; Weldon et al., 2021). During practical training sessions,

the emphasis is placed on cultivating muscle strength and explosive power, prompting the muscles to rapidly contract and shorten. In the context of soccer, this type of training aids in the development of muscular strength and endurance, enabling players to execute physically demanding actions. Additionally, this exercise is frequently incorporated into athletic training programs to enhance running speed by exerting stress on crucial muscles like the hips and knees (Cronin & Hansen, 2006). The training program should be specific and verities. It can help soccer players improve their agility that were related to overall soccer performance (Thongnum & Phanpheng, 2022). Collaboration between trainers, researchers, and practitioners is needed to cover the deficiencies above. The coach must be involved in developing research and theory to improve the quality of training planning.

Presently, the scientific literature offers scarce evidence regarding the relationship between anthropometric characteristics and the effects of speed training. This study aims to provide valuable insights into the specific anthropometric traits that influence a player's response to the training regimen. Furthermore, the comparative impact of practicing a single weekly plyometric session in conjunction with either sided jump sprint (SJS) training or uphill sprint training (UHS) remains relatively unexplored. This research has the potential to contribute towards the development of more effective training strategies and the adoption of a more personalized approach to optimize running speed performance within the context of soccer.

## Materials and methods

### Study participants

A total of 100 male soccer students aged 18 to 19 years became the population in this study. 60 samples were selected as samples using a purposive random sampling technique. Of the 60 samples, 30 received UHS training, and 30 received SJS training. Furthermore, each exercise group was divided into three groups based on the value of the large, medium, and small anthropometric ratios. Each group consists of 10 samples, with the group division technique using a stratified random sampling technique.

### Study organization

The method used in this study is an experimental method with a 2×3 factorial design, where the UHS and SJS training methods are the independent variables, the small, medium, and large anthropometric ratios are the attribute variables, and the 20-meter running speed is the dependent variable. This 2×3 factorial design will allow observation of the interaction between the training method and the ratio of sitting height to standing height on the soccer player's sprint performance. After completing the pretest, the subjects underwent separate training between UHS and SJS. Both groups did exercises with the same frequency thrice a week for six weeks. The sprint distance during the exercise used by each group is 20 meters using high intensity. The UHS sprint exercise is carried out on an uphill area with a slope of approximately 8% (Delaney et al., 2022). SJS exercises use a hurdle with a height of 40 cm. The exercises were carried

out for six weeks with a frequency of three times a week. Six weeks of training can improve physical abilities (Kumar & Pandey, 2023).

### Statistical analysis

The data collection techniques included measuring sitting and standing height and a 20-meter sprint test to measure sprint performance. The collected data were analyzed using the Analysis of Variance (ANOVA) test with a 2x3 factorial design at a significance level of  $\alpha = 0.05$ . Previously, a normality test (Shapiro Wilk test) was carried out to ensure the data met the assumption of normality and a homogeneity test of variance (Levene's test) to ensure homogeneity of variance between groups.

### Results

This research was conducted for one month and a half, with a total of 20 days of practice with details of one pretest, 18 treatments, and one post-test. The number of participants is as many as 60 players. The results of calculating speed ability are obtained as follows.

It is descriptive statistical data in this study. The results of Table 1 above, show that the SJS training model has the greatest increase, namely  $0.399 \pm 0.157$ . The anthropometric

**Table 1.** Data Description

| Anthropometry Group | Training Model    | Mean   | Std. Deviation | N  |
|---------------------|-------------------|--------|----------------|----|
| Small               | Sided Jump Sprint | 0.4920 | 0.10799        | 10 |
|                     | Up Hill Sprint    | 0.5100 | 0.09262        | 10 |
|                     | Total             | 0.5010 | 0.09835        | 20 |
| Medium              | Sided Jump Sprint | 0.4820 | 0.09496        | 10 |
|                     | Up Hill Sprint    | 0.2830 | 0.09604        | 10 |
|                     | Total             | 0.3825 | 0.13806        | 20 |
| Large               | Sided Jump Sprint | 0.2240 | 0.09107        | 10 |
|                     | Up Hill Sprint    | 0.1780 | 0.05884        | 10 |
|                     | Total             | 0.2010 | 0.07826        | 20 |
| Total               | Sided Jump Sprint | 0.3993 | 0.15783        | 30 |
|                     | Up Hill Sprint    | 0.3237 | 0.16266        | 30 |
|                     | Total             | 0.3615 | 0.16342        | 60 |

The data are presented by means  $\pm$  SD.

**Table 2.** Normality Test

| Training Model          | Group  | N  | M      | SD      | A    | Sig   | Result |
|-------------------------|--------|----|--------|---------|------|-------|--------|
| Up Hill Sprint (UHS)    | Small  | 10 | 0.5100 | 0.09262 | 0.05 | 0.199 | Normal |
|                         | Medium | 10 | 0.2830 | 0.09604 | 0.05 | 0.595 | Normal |
|                         | Large  | 10 | 0.1780 | 0.05884 | 0.05 | 0.431 | Normal |
| Sided Jump Sprint (SJS) | Small  | 10 | 0.4920 | 0.10799 | 0.05 | 0.263 | Normal |
|                         | Medium | 10 | 0.4820 | 0.09496 | 0.05 | 0.558 | Normal |
|                         | Large  | 10 | 0.2240 | 0.09107 | 0.05 | 0.390 | Normal |

The data are presented by means  $\pm$  SD and sig. value; In the Shapiro-Wilk test, the data is normally if the sig.  $\geq 0.05$ .

group with a small ratio has the largest result, namely  $0.501 \pm 0.098$ .

Table 2. Shows the results of the normality test using the Shapiro-Wilk test. Based on the output of Table II above, it is known to have a sig value  $> 0.05$ , so it can be concluded that the UHS Training model data and Sided Jump Sprint with small, medium, and large anthropometric characteristics are normally distributed.

Levene's test determines whether each variant of the dependent variable is the same or homogeneous. Based on Table 3 above, it is known that the sig. Based on the respective mean of 0.276 and 0.675  $> 0.05$ , it can be concluded that the variance of the data resulting from the SJS training model and the UHS training model is homogeneous.

Based on the output results in Table 4. Then the results of testing the hypothesis can be concluded as follows. The first hypothesis, based on the output, is a sig value of  $0.002 < 0.05$ , so there is a difference in the increase in running speed of 20 m based on the 2 training models. The second hypothesis, based on the output, is a sig value of  $0.000 < 0.05$ , so there is a difference in the increase in running speed of 20 m based on anthropometric characteristics. The third hypothesis, based on the output, is a Sig value of  $0.001 < 0.05$  so that there is an interaction between the training model and anthropometric characteristics in increasing the running speed of 20 m.

**Table 3.** Homogeneity Test

| Group                  | A    | Sig   | Result      |
|------------------------|------|-------|-------------|
| Up Hill Sprint (UHS)   | 0.05 | 0.276 | Homogeneous |
| Side Jump Sprint (SJS) | 0.05 | 0.675 | Homogeneous |

The data are presented by significant value; In the Levene's test, the data is homogeneous if the sig.  $\geq 0.05$ .

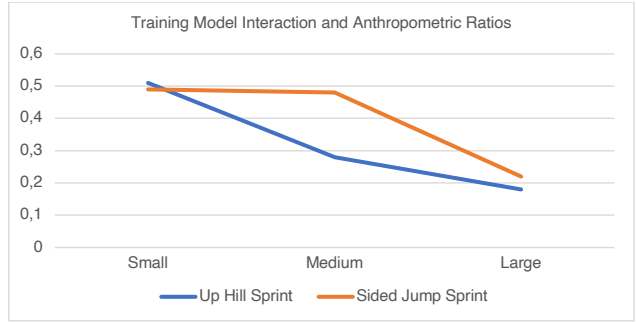


**Fig. 1.** Interaction Plot Diagram of training models and anthropometric ratios

**Table 4.** Anova Two Way Test

| Tests of Between-Subjects Effect     |                         |    |             |         |       |
|--------------------------------------|-------------------------|----|-------------|---------|-------|
| Dependent Variable : Sprint 20 meter |                         |    |             |         |       |
| Source                               | Type III Sum of Squares | Df | Mean Square | F       | Sig.  |
| Corrected Model                      | 1.123 <sup>a</sup>      | 5  | 0.225       | 26.835  | 0.000 |
| Intercept                            | 7.841                   | 1  | 7.841       | 936.480 | 0.000 |
| Group                                | 0.913                   | 2  | 0.457       | 54.536  | 0.000 |
| Training_Model                       | 0.086                   | 1  | 0.86        | 10.257  | 0.002 |
| Group* Training_Model                | 0.124                   | 2  | 0.62        | 7.424   | 0.001 |
| Error                                | 0.452                   | 54 | 0.008       |         |       |
| Total                                | 9.417                   | 60 |             |         |       |
| Corrected Total                      | 1.576                   | 59 |             |         |       |

a. R Squared = .713 (Adjusted R Squared = .686)

The data are presented by means  $\pm$  SD; \*statistically significant difference when compared within group, mean scores at point comparisons from baseline: \*  $p \leq 0.05$  and \*t  $p \leq 0.01$  when comparing the difference between experimental group.

Figure I. The above is useful for assessing whether there is an interaction effect between variables. However, this diagram cannot be used as a valid reference. However, to give an overview of the interactions that occur. An interaction effect is suspected if the lines do not show parallels. The diagram above shows a misalignment of the lines, so it is suspected that there is an interaction effect between the training model and the anthropometric ratio

The study results should be presented in tables and described in a logical sequence.

## Discussion

The results of testing the first hypothesis indicate a significant difference in the effect of the UHS and SJS training models on the 20-meter sprint performance. In this study, the group that underwent the SJS training model showed a better increase in running speed than the group that underwent the UHS training model. This finding can be explained through several relevant reinforcement theories. First, the speed-solidity principle states that to achieve maximum speed, it is important to develop sufficient muscle strength (Kenney et al., 2021; Kusnanik, 2011). The SJS training model, which emphasizes developing leg muscle strength and explosive power, conforms to this principle. By training the muscles involved in sprinting movements, we can increase the strength and explosive power needed to reach maximum speed (Ramirez-Campillo et al., 2020). Second, the specificity theory states that specific training by the goals will give better results (Harsono, 2018; Sidik et al., 2019; Tudor, 2019). The SJS training model is designed to increase running speed, focusing on technique and movements similar to the 20-meter sprint.

Previous research has shown that running and jumping are the most frequent actions before scoring situations, and, most importantly, sprint distance and maximal sprint count have increased substantially in professional soccer over the past few years (Bush et al., 2015). Therefore, this exercise specifically prepares students for the physical and technical demands they will face. In addition, the theory of functional adaptation explains that the body will adapt to regular

exercise by developing the physiological systems needed to meet the demands of the exercise (Kenney et al., 2021; Kusnanik, 2011). The SJS training model, which involves speed and explosive power training, will stimulate the body's physiological adaptations that align with the 20-meter sprint. The stretching-shortening cycle, enhanced by the exercise, is a major adaptation contributing to improved athlete performance. This adaptation is due to increased stiffness at the muscle-tendon junction and more efficient use of the elastic component of the muscle. The muscles will become stronger, the anaerobic energy system will improve, and the coordination of body movements will improve. In line with the results of a study Loturco et al. (2015) who demonstrated that plyometric training has an important role in influencing neuromechanical responses in high-level soccer players. In the context of this study, neuromechanics refers to the changes that occur in soccer players' nervous and muscular systems in response to plyometric training, this includes neuromuscular adaptations, such as increased strength, explosive power, and jumping ability, which can improve players' sprint and jumping performance. Finally, the theory of anaerobic training states that training with high intensity and focus on anaerobic training will involve the body's anaerobic energy system, which is important in achieving high running speeds (Assunção et al., 2018; Kenney et al., 2021). In line with this, according to Andrzejewski et al. (Andrzejewski & Chmura, 2008) the speed of soccer players requires high-speed maintenance through an energy regeneration process that involves the breakdown of phospho-creatine and free oxygen glycolysis. Another study found that a combined plyometric and sprint training program in soccer practice had a positive effect on the explosive and technical actions of soccer players during a competitive season, with significant increases in jumping ability, sprinting, change of direction, and ball shooting speed (Ceylan & Demirkan, 2017; Sáez De Villarreal et al., 2015). Similar studies have also found that training with speed affects anaerobic capacity in soccer players (Kusnanik et al., 2019).

The results of testing the second hypothesis indicate that the anthropometric ratio significantly affects the 20-meter

running performance. Biomechanical theory can be used to explain this phenomenon. According to biomechanical theory, stride length while running is directly related to running speed (Huston, 2013; Knudson, 2007; Sudarmada & Wijaya, 2015). The principle of balance influences the anthropometric ratio of sitting height and standing height. The difference in the sitting and standing height ratio will affect the center of gravity and coordination of body movements. Someone with a small ratio of sitting height to standing height tends to have longer limbs, affecting the center of gravity and body stability when jumping in exercise. The balance will be maintained when a person has the correct movement and distribution of body mass to provide a mechanical advantage (Huston, 2013; Knudson, 2007; Sudarmada & Wijaya, 2015). In addition, anthropometric theory can also be applied in this context. The ratio of sitting height and standing height reflects the proportions of a person's body (Preedy, 2012). Someone with a small ratio of sitting height to standing height tends to have more ideal body proportions to achieve high running speed. The longer body proportions in the limbs provide an advantage in producing longer, more efficient strides while running.

It should be noted that although the ratio of sitting to standing height has a significant effect, other factors can also play a role in 20-meter running performance. General fitness, upper body muscle strength, running technique, and genetic factors also affect sprint performance (Campa et al., 2019). Therefore, in training and developing running speed, it is necessary to consider these factors holistically.

The results of testing the third hypothesis showed a significant difference in the effect of training models and the ratio of sitting height to standing height on the performance of the 20-meter sprint. Interesting things were found in this study, although previous explanations concluded that the SJS model has advantages over the UHS. However, if it is related to anthropometric characteristics, UHS has a significant impact when applied to players with anthropometric characteristics with a height ratio, this can be explained by functional adaptation theory and specific fitness theory. Functional adaptation theory explains that the human body has the ability to adapt to certain training stimuli (Kenney et al., 2021; Kusnanik, 2011). The UHS training model, which emphasizes leg muscle strength and anaerobic speed endurance, provides an appropriate stimulus for students with a small ratio of sitting height to standing height. Their body proportions that allow for longer and more efficient strides provide a mechanical advantage in increasing running speed. However, the case is different if UHS is applied to anthropometric characteristics with medium and high ratios. Training will not be efficient because players need help maintaining balance when running on uphill terrain. If forced, it will have an impact on joint injuries and others.

On the other hand, the SJS model conforms to all anthropometric characteristics. The SJS training model, which focuses on developing leg muscle strength and explosive power, provides a more effective stimulus for students with these body proportions. With straight terrain, players will have no trouble doing this exercise. In line with research which states that plyometric exercises are suitable for use on flat surfaces or grass (Marzouki et al., 2022; Pereira et al., 2023). Thus, they can achieve a significant increase in running speed. In addition, anthropometric theory can

also provide a deeper understanding. The ratio of sitting height to standing height reflects the length ratio between the upper and lower parts of the body (Preedy, 2012). In line with research conducted by Bongiovanni et al. (2021) who found that anthropometric features of the upper and lower body were significantly related to sprint performance and aerobic fitness in young elite soccer players.

## Conclusions

The SJS training model has advantages in increasing the running speed by 20 meters. However, if we look at the anthropometric characteristics, UHS training is highly recommended for players with a small ratio of anthropometric characteristics. Through developing muscle strength, specific exercises, functional adaptations, biomechanical principles, and anaerobic exercises, students can significantly increase their 20-meter sprint performance. These results provide important insights for coaches and athletes in designing suitable training programs. Introducing the sitting and standing height ratio of students and adjusting individual training programs can help improve sprint performance.

## Conflict of interest

Authors do not receive endorsement from any organization for submitted work. The author has no relevant financial or non-financial interest to disclose.

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# ДИФЕРЕНЦІАЛЬНИЙ ВПЛИВ ВПРАВ ЗІ СПРИНТУ ВГОРУ ТА СПРИНТУ ЗІ СТРИБКАМИ ВБІК І РІЗНИХ АНТРОПОМЕТРИЧНИХ ХАРАКТЕРИСТИК НА ШВИДКІСТЬ ФУТБОЛІСТІВ

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

Реферат. Стаття: 8 с., 4 табл., 1 рис., 50 джерел.

**Мета дослідження.** Для підвищення швидкості бігу футболістів під час вибору моделі тренувань потрібно брати до уваги антропометричні фактори.

**Матеріали та методи.** У цьому дослідженні використовували експериментальний метод із факторним планом 2×3. Для відбору вибірки із 60 учасників із генеральної сукупності 100 осіб використовували метод цільової випадкової вибірки. Потім вибірку розділили на шість груп за допомогою методу стратифікованої випадкової вибірки (велике співвідношення антропометричних параметрів (САП), спринт угору (СУ), n = 10 учасників; середнє САП, СУ, n = 10 учасників; невелике САП, СУ, n = 10 учасників; велике САП, спринт зі стрибками вбік (ССВ), n = 10 учасників; середнє САП, ССВ, n = 10 учасників; невелике САП, ССВ, n = 10 учасників). Як інструменти збору даних використовували тест на швидкість бігу на 20 метрів та антропометричні параметри. Для аналізу даних використовували двофакторний дисперсійний аналіз і тести на нормальність і однорідність як передумови.

**Результати.** Результати дослідження показали наявність статистично значущих відмінностей у двох моделях тренувань зі значенням показника значущості  $0,002 < 0,05$ ; наявність статистично значущих відмінностей у трьох антропометричних групах зі значенням показника значущості  $0,000 < 0,05$  та наявність взаємовпливу між моделлю тренувань та антропометричними характеристиками в контексті підвищення швидкості бігу на 20 метрів зі значенням показника значущості  $0,001 < 0,05$ .

**Висновки.** Результати цього дослідження дозволяють дійти висновку, що модель тренувань ССВ підходить для трьох рівнів співвідношень антропометричних параметрів, тоді як модель СУ дуже підходить для учасників із невеликим САП. Також на підставі результатів цього дослідження можна дійти висновку, що невелике співвідношення антропометричних параметрів мало найбільший вплив на швидкість бігу на 20 метрів.

**Ключові слова:** спринт угору, спринт зі стрибками вбік, антропометрія, швидкість бігу на 20 метрів, футбол.

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ORIGINAL SCIENTIFIC ARTICLE

## THE EFFECT OF AN 8-WEEK ONLINE HIGH-INTENSITY INTERVAL TRAINING PROGRAM ON BODY COMPOSITION AND PERFORMANCE IN THAI PROFESSIONAL FOOTBALL PLAYERS DURING THE COVID-19 EPIDEMIC

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### Abstract

**Background/objectives.** High-intensity interval training (HIIT) was used to be a strategy for improving physical performance. Especially, athletic training which were disturbed by the Covid-19 pandemic. Therefore, the objectives of this study were to determine the effects of an 8-week online HIIT program on the body composition, aerobic and anaerobic performances in professional football players.

**Materials and methods.** Thirty professional football players in Thai league division 2 were randomly assigned into the onsite group (n = 15) and the online group (n = 15). All participants performed the HIIT program at 85% maximal heart rate (HRmax), five times a week for 8 weeks. Body composition, aerobic and anaerobic performance at baseline, after 4 weeks and 8 weeks of training were calculated by repeated measures ANOVA and unpaired t-test.

**Results.** Weight, BMI and % fat were significantly decreased after 4 weeks of training in the onsite group and after 8 weeks of training in the online group ( $p < 0.05$ ). FFM in the onsite and online groups was significantly increased after 4 weeks and 8 weeks of training, respectively ( $p < 0.05$ ). Aerobic performance was significantly increased after 4 and 8 weeks of training ( $p < 0.05$ ), whereas anaerobic performance was found increased after 8 weeks of training in both groups ( $p < 0.05$ ). There were no significant differences between the groups.

**Conclusions.** Eight weeks of HIIT training can improve body composition, aerobic performance and anaerobic performance in both onsite and online conditions. It may be implied that an online HIIT training program should have beneficial effects similar to those provided in onsite condition.

**Keywords:** HIIT program, aerobic performance, anaerobic performance, soccer.

### Introduction

The outbreak of the COVID-19 pandemic has presented significant challenges in managing various aspects of human life, including physical activities worldwide. Among the strategies employed to control the spread of COVID-19, social distancing measures have been widely implemented (Wang et al., 2020; Tsolakis et al., 2023). Unfortunately, these measures have disrupted the routines of athletes, affecting their training, skill development, and competitive opportunities (Fitzgerald et al., 2021). As a result, athletes have encountered difficulties in achieving their targeted exercise and training routines, often resorting to general

physical well-being and health maintenance due to limited access to equipment and facilities. Consequently, key training factors such as intensity, duration, frequency, and mode have suffered notable reductions (Fitzgerald et al., 2021). For athletes engaged in high-intensity athletic activities, inadequate training can lead to detraining effects.

Football, being an intermittent sport involving a variety of high-intensity movements such as rapid changes in direction, sprinting, and jumping, has been particularly affected by the off-season period resulting from COVID-19 lockdowns (Radzimiński et al., 2021). Previous studies have also highlighted the negative impact of home isolation during the pandemic on athletes' aerobic capacity, muscle strength, muscle mass, body fat, and exercise performance (Tsolakis et al., 2023; Parpa & Michaelides, 2021). In this context, high-intensity interval training (HIIT), characterized by brief

intervals of vigorous activity combined with periods of low activity or rest, has emerged as a valuable tool for enhancing health and performance across diverse populations. HIIT's aim is to accumulate activity at an intensity that the participant would be unable to tolerate for prolonged periods (i.e. 80-95% of peak oxygen consumption ( $\text{VO}_{2\text{peak}}$ ) or >90% of maximum heart rate ( $\text{HR}_{\text{max}}$ ), therefore the recovery time should be enough to allow the subsequent interval to be completed at the desired intensity (Cassidy et al., 2017). HIIT was used to be a tool for improving health and performances in many target groups (Gillen & Gibala, 2014) such as healthy untrained overweight/obese males (Khammassi et al., 2018), overweight/obese untrained individuals (Gripp et al., 2021), overweight and obese women, 10 sedentary young females (Lu et al., 2022), futsal players (Marzieh et al., 2016). HIIT is a novel interval strategy that has recently piqued the interest of athletes which can increase physical fitness in athletes. The effect of HIIT on bioenergetic variables in professional football players has received little attention (Marzieh et al., 2016). Other study also found that 12 weeks of HIIT, BMI and fat mass percentage were dramatically reduced. In addition, HIIT can improve cardiopulmonary fitness in healthy untrained overweight/obese youth (Khammassi et al., 2018). According to Covid-19 pandemic, a home-based exercise training program was considered to be an instrument for conserving and improving health as well as performance in athletes. Especially, HIIT is an interesting training programs for this pandemic. There are many factors that affect to reach the goal of home-based exercise training program including individual's concentration and the environment such as limited space of the room for training. Therefore, the researcher tries to find out the online HIIT Program to assist athletes maintain and enhance their performances of professional football players during the COVID-19 pandemic. Thus, the objectives of this study were to determine the effects of an 8-week online high intensity interval training (HIIT) program on the body composition, aerobic and anaerobic performances in professional Thai football players during the Covid-19 pandemic.

## Material and methods

### Participants

A total of thirty professional football players from Rajpracha F.C. Football club, competing in the Thai League Division 2, were recruited for this study. The participants were randomly assigned to one of two groups: Group 1, the onsite group (control group,  $n = 15$ ), and Group 2, the online group (experimental group,  $n = 15$ ). The recruitment process adhered to ethical standards outlined in the Helsinki Declaration, and the study protocol received full approval from Walailak University (WUEC-22-317-01). Prior to the commencement of the experiment, all participants were provided with a detailed explanation of the procedures involved as well as the associated risks. Inclusion criteria for participation included the players' informed consent, absence of any illness records, and a minimum of six months of training experience. Exclusion criteria consisted of training-related injuries and a consecutive absence from two sessions or a non-consecutive absence from three sessions.

### Experimental protocol

Upon completion of the consent form, participants underwent a series of assessments to determine their anthropometric measurements (height, weight, BMI), body composition (% fat, fat-free mass; FFM), aerobic performance (YO-YO test;  $\text{VO}_{2\text{max}}$ ), and anaerobic performance (RAST test; maximal power, minimal power, average power, and fatigue index) at baseline. These parameters were assessed again at 4 weeks and 8 weeks following the training intervention. The participants then commenced an 8-week high-intensity interval training (HIIT) program, which was conducted either onsite or online, depending on the assigned group. The HIIT program was designed to be performed at 85% of maximum heart rate ( $\text{HR}_{\text{max}}$ ) and consisted of five training sessions per week: Monday, Wednesday, and Friday sessions included six exercise modalities (Squat Jump, Mountain climbers, Step in-out, Push hand up, High Knee up, Burpee), while Tuesday and Thursday sessions involved different exercises (Jumping jack, Bicycle crunch, Slide L-R, Planking jack, Jump lunge, Burpee). Each session lasted for a total of five minutes, with four minutes of resting time between sessions.

During weeks 1-4 of the program, participants performed each exercise for 50 seconds, followed by a 30-second rest interval. From weeks 5-8, the exercise duration was increased to 60 seconds, with the same 30-second rest interval. The warm-up protocol included a combination of static and dynamic stretching exercises lasting for 10 minutes, while the cool-down protocol consisted of static stretching exercises performed for 8 minutes. Anthropometric measurements (height, weight, BMI) and body composition (% fat, FFM) were assessed using a Bioelectrical Impedance Analysis (Tanita SC330S Body Composition Scale). Aerobic performance ( $\text{VO}_{2\text{max}}$ ) was evaluated using the Yo-Yo test, a well-established field test for measuring maximal oxygen consumption (Chaouachi et al., 2012). Anaerobic performance (maximal power, minimal power, average power, and fatigue index) was assessed using the RAST (Running-based Anaerobic Sprint Test) protocol, which involved a series of maximal sprint efforts (Draper & Whyte, 1997). To ensure the accuracy and reliability of the measurements, standardized protocols and procedures were followed consistently throughout the study, adhering to established guidelines for each assessment. The research team was responsible for conducting the assessments and recording the data in a systematic and unbiased manner. The collected data from the assessments at baseline, 4 weeks, and 8 weeks were used to evaluate the effects of the HIIT program on the selected variables, allowing for comparisons between the onsite and online groups. Statistical analysis was performed to determine the significance of any observed changes and to assess the overall impact of the HIIT intervention on the participants' anthropometry, body composition, aerobic performance, and anaerobic performance.

### Statistical analysis

Data were expressed as mean  $\pm$  S.D. by using SPSS version 26 was used to test the statistics. Repeated measure ANOVA was used to compare all parameters between times, Turkey's

post hoc test were applied in case of significant ( $P < 0.05$ ). F ratio to locate the differences. Unpaired t test was used to identify condition differences between parameters.  $P < 0.05$  was considered significant.

## Results

### Baseline characteristic parameters

All participants had normal levels of BMI (onsite group;  $22.74 \pm 2.51$  and online group;  $23.31 \pm 1.96$  kg/m<sup>2</sup>), % fat (onsite group;  $8.62 \pm 3.54$  and online group;  $10.18 \pm 3.19$  %) and FFM (onsite group;  $64.62 \pm 7.78$  and online group;  $67.11 \pm 8.70$  kg). There were no significant differences in anthropometric and body composition variables between onsite and online group at before training (Table 1).

**Table 1.** Baseline characteristics of participants

| Variables                | Onsite (n = 15)   | Online (n = 15)   |
|--------------------------|-------------------|-------------------|
| Age (Yr)                 | 23.87 $\pm$ 5.32  | 23.07 $\pm$ 5.60  |
| Height (m)               | 1.76 $\pm$ 0.07   | 1.79 $\pm$ 0.09   |
| Weight (kg)              | 70.97 $\pm$ 10.21 | 74.99 $\pm$ 11.28 |
| BMI (kg/m <sup>2</sup> ) | 22.74 $\pm$ 2.51  | 23.31 $\pm$ 1.96  |
| % Fat (%)                | 8.62 $\pm$ 3.54   | 10.18 $\pm$ 3.19  |
| FFM (kg)                 | 64.62 $\pm$ 7.78  | 67.11 $\pm$ 8.70  |

Data are expressed as mean  $\pm$  SD., BMI – Body mass index; FFM – Fat free mass

### Body Composition, Aerobic and Anaerobic performance

The onsite group had significantly lower weight and BMI after 4 weeks of training than before training ( $p < 0.05$ ). Moreover, the online group also had significantly lower weight and BMI after 8 weeks than after 4 weeks of training ( $p < 0.05$ ). The percentage of fat in onsite group had significantly lower after 8 weeks than before training ( $p < 0.05$ ), in addition, it was also found in online group after 8 weeks than after 4 weeks and before training ( $p < 0.05$ ). FFM had significantly higher after 4 weeks than before training in onsite group ( $p < 0.05$ ), it was also reported in online group after 8 weeks than after 4 weeks of training ( $p < 0.05$ ).

Aerobic performance in both groups had significantly higher after 4 and 8 weeks of training than before ( $p < 0.05$ ). Whereas, anaerobic performance in both groups had significantly higher after 8 weeks of training than before ( $p < 0.05$ ) which were seen in max and min power parameters. Furthermore, the online group had significantly higher in average power after 8 weeks than 4 weeks and before training ( $p < 0.05$ ). There were no any changes in fatigue index in both groups. However, there were no significant differences in body composition, aerobic performance and anaerobic performance variables between onsite and online group at any time of training (Table 2).

## Discussion

The results of this study showed that body composition, aerobic and anaerobic performance were improved after HIIT training for 8 weeks in both onsite and online condition. Nevertheless, the online condition seems to be gradually increased in these parameters when compared to the onsite condition. Previous studies suggested that HIIT program was used to be an implement for improving health and performances in many individuals such as overweight/obese healthy untrained (Khammassi et al., 2018), overweight/obese untrained (Gripp et al., 2021), overweight and obese women (Nobari et al., 2022), sedentary young females (Lu et al., 2022), and futsal players (Marzieh et al., 2016). Especially, Covid-19 pandemic disturbed the maintaining and improving of the performances in athletes. Therefore, examination of the online HIIT training program affected on many aspects in athletics were considered.

This study reported that body composition for instance weight, BMI, % fat and FFM in both onsite and online condition were improved after training, which was found at 4 weeks after exercise in onsite group while it was found at 8 weeks after exercise in online group. In addition, aerobic and anaerobic performance were also improved after the training for 8 weeks in both groups. These findings were similar to the earlier studies, Balbasi and colleagues (2016) examined the effect of 3-week HIIT on body composition, maximum aerobic power and maximum anaerobic power in boys - futsal players. They reported that HIIT program with 3 sessions per week affected the reduction of weight,

**Table 2.** Body composition, Aerobic and Anaerobic performance in onsite and online group

| Variables                | Onsite (n = 15)     |                     |                         | Online (n = 15)     |                     |                         |
|--------------------------|---------------------|---------------------|-------------------------|---------------------|---------------------|-------------------------|
|                          | Before              | 4 wk                | 8 wk                    | Before              | 4 wk                | 8 wk                    |
| Weight (kg)              | 70.97 $\pm$ 10.21   | 70.64 $\pm$ 9.87*   | 70.93 $\pm$ 10.01       | 74.99 $\pm$ 11.28   | 74.46 $\pm$ 10.47   | 75.09 $\pm$ 10.70**     |
| BMI (kg/m <sup>2</sup> ) | 22.74 $\pm$ 2.51    | 22.64 $\pm$ 2.45*   | 22.73 $\pm$ 2.45        | 23.31 $\pm$ 1.96    | 23.16 $\pm$ 1.70    | 23.36 $\pm$ 1.82**      |
| % Fat (%)                | 8.62 $\pm$ 3.54     | 7.68 $\pm$ 2.75     | 7.76 $\pm$ 2.93*        | 10.18 $\pm$ 3.19    | 9.03 $\pm$ 2.67*    | 8.56 $\pm$ 2.34*,**     |
| FFM (kg)                 | 64.62 $\pm$ 7.78    | 65.05 $\pm$ 7.96*   | 65.23 $\pm$ 7.85        | 67.11 $\pm$ 8.70    | 67.52 $\pm$ 8.33    | 68.52 $\pm$ 8.91**      |
| YOYO (ml/kg/min)         | 49.59 $\pm$ 2.86    | 52.94 $\pm$ 3.04*   | 56.29 $\pm$ 3.17*,**    | 49.10 $\pm$ 3.50    | 53.17 $\pm$ 3.08*   | 57.01 $\pm$ 2.83*,**    |
| Max Power (watt)         | 913.83 $\pm$ 182.01 | 928.79 $\pm$ 180.93 | 950.36 $\pm$ 173.71*,** | 943.74 $\pm$ 234.44 | 949.15 $\pm$ 226.06 | 977.31 $\pm$ 227.40*    |
| Min Power (watt)         | 631.43 $\pm$ 144.89 | 638.51 $\pm$ 123.15 | 658.89 $\pm$ 122.63*    | 614.82 $\pm$ 164.54 | 635.21 $\pm$ 160.30 | 665.39 $\pm$ 164.85*,** |
| Average Power (watt)     | 762.81 $\pm$ 145.21 | 765.72 $\pm$ 139.14 | 775.42 $\pm$ 132.35     | 778.34 $\pm$ 202.26 | 783.95 $\pm$ 199.38 | 809.40 $\pm$ 197.71*,** |
| Fatigue Index (%)        | 9.72 $\pm$ 5.29     | 10.03 $\pm$ 4.35    | 10.10 $\pm$ 3.64        | 11.15 $\pm$ 4.24    | 10.69 $\pm$ 3.72    | 10.71 $\pm$ 3.55        |

Data are expressed as mean  $\pm$  SD.; BMI – Body mass index; FFM – Fat free mass; \* Significantly different compared to before training ( $p < 0.05$ ); \*\* Significantly different compared to 4 weeks of training ( $p < 0.05$ )

BMI and % fat in experiment group after training (Marzieh et al., 2016). Khammassi and co-workers (2018) investigated the effects of 12 weeks of HIIT program without caloric restriction on aerobic capacity, body composition and lipid profile in twenty healthy young overweight/obese men. They found that the HIIT program comprised of 3 exercises sessions per week (30 sec of work at 100% maximal aerobic velocity) improved aerobic capacity ( $VO_{2max}$ ), body composition (BMI, waist circumference, % fat) and lipid profile (Khammassi et al., 2018). Gripp and co-worker (2020) suggested that HIIT improved indicators of cardiometabolic health such as  $VO_{2max}$ , BMI, body fat, visceral fat after 8 weeks of training in healthy overweight/obese untrained individuals. The benefit effects of the HIIT program were also institute to be longer lasting and maintained after the holdup of high-intensity interval running for 4 weeks (Gripp et al., 2021). Moreover, Lu and co-worker (2022) also studied the effects of 8-week high-intensity interval training and moderate-intensity continuous training on body composition,  $VO_{2max}$  and bone metabolism in sedentary young females. They also found that the HIIT program could improve weight, BMI, % fat and  $VO_{2max}$  after the training in HIIT group (Lu et al., 2022). The beneficial consequences of HIIT training program on health and cardiorespiratory fitness were considered in many situations such as athletic and metabolic health. It was well-known that HIIT can affect the cardiometabolic health (Cassidy et al., 2017), specially, the changes in skeletal muscle via increased muscle work capacity, oxidative capacity and glucose transport. Furthermore, there were evidences supported that HIIT could induce positive effects on body composition, particularly, fat loss through possible mechanism for instance 1) increased mitochondrial density and capacity following HIIT caused increasing of fat oxidation rate (Talanian et al., 1985), 2) great raises in catecholamines, which have been shown to motivate lipolysis (Zouhal et al., 2008) exclusively, in the abdominal tissue where there are significantly more  $\beta$ -adrenergic receptors, compared with subcutaneous fat (Rebuffé-Scrive et al., 1989), 3) appetite suppression (Sim et al., 2014).

Besides, it could be said that the most important outcome following HIIT training is cardiorespiratory fitness, which examined by  $VO_{2max}$ .  $VO_{2max}$  is the gold standard parameter of fitness and a strong indicator of how well the cardiac, pulmonary, vascular and peripheral systems are working together. Previous studies have been shown that HIIT improves the capacity of both aspects of the oxygen supply and demand chain, nonetheless it is the cardiovascular adaptations in response to HIIT that are more likely to leading to  $VO_{2max}$  enhancement (Baekkerud et al., 2016).

On the other hand, recent study in 2022 reported that 8 weeks of HIIT program combined with Spirulina Supplementation could not affect to weight, BMI and % fat in sedentary overweight/obese women while FFM was lower after the training (Nobari et al., 2022). However, there were many factors that affected the efficacy of HIIT program such as a complicated training protocol and psychological factors (mood, motivation, perception of effort, etc.) (Khammassi et al., 2018; Gibala, 2007).

### Limitation

The limitation of this study was to the participants did not undergo the caloric restriction during training, which

directly to affected body composition parameters. It may be leading to there were no significant differences outcomes between onsite and online groups.

### Conclusions

In conclusion, 8 weeks of HIIT training can improve body composition, aerobic performance and anaerobic performance in both the onsite and online groups. Likewise, there were no significant different between onsite and online condition, it may be implied that online HIIT training program have similar beneficial effects to onsite condition. Nevertheless, the online condition seems to be slower improvement of all outcomes than the onsite. It may be due to the factors that affect to reach the goal of home-based exercise training program including individual's concentration and the environment such as limited space of the room for training.

### Conflicts of interest

The authors declare that there is no conflict of interest.

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# ВПЛИВ 8-ТИЖНЕВОЇ ІНТЕРАКТИВНОЇ ПРОГРАМИ ВИСОКОІНТЕНСИВНИХ ІНТЕРВАЛЬНИХ ТРЕНУВАНЬ НА СКЛАД ТІЛА ТА РЕЗУЛЬТАТИВНІСТЬ ТАЙСЬКИХ ПРОФЕСІЙНИХ ФУТБОЛІСТІВ ПІД ЧАС ЕПІДЕМІЇ COVID-19

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

Реферат. Стаття: 6 с., 2 табл., 22 джерела.

**Історія питання та мета дослідження.** Високоінтенсивні інтервальні тренування (ВІІТ) використовували як стратегію для покращення фізичних показників. Зокрема, спортивні тренування, яким завадила пандемія Covid-19. Таким чином, метою цього дослідження було визначити вплив 8-тижневої інтерактивної програми ВІІТ на склад тіла, аеробні та анаеробні показники професійних футболістів.

**Матеріали та методи.** Тридцять професійних футболістів зі складу 2-го дивізіону тайської ліги методом випадкової вибірки розподілили на фізичну групу (n = 15) та інтерактивну групу (n = 15). Усі учасники виконували програму ВІІТ на рівні 85% максимальної частоти серцевих скорочень (МЧСС) п'ять разів на тиждень протягом 8 тижнів. Склад тіла, аеробні та анаеробні показники на вихідному рівні, після 4 тижнів і 8 тижнів тренувань розраховували за допомогою дисперсійного аналізу повторних вимірювань і двовибіркового t-критерію Стьюдента для незалежних вибірок.

**Результати.** Показники ваги, ІМТ та % жиру в організмі статистично значуще знизилися після 4 тижнів тренувань у фізичній групі та після 8 тижнів тренувань в інтерактивній групі (p < 0,05). Показник маси тіла без жиру у фізичній та інтерактивній групах статистично значуще збільшився після 4 та 8 тижнів тренувань відповідно (p < 0,05). Аеробна продуктивність статистично значуще зросла після 4 та 8 тижнів тренувань (p < 0,05), тоді як анаеробна продуктивність зросла після 8 тижнів тренувань в обох групах (p < 0,05). Статистично значущих відмінностей між групами не було.

**Висновки.** Вісім тижнів занять ВІІТ можуть покращити склад тіла, аеробну та анаеробну продуктивність як у фізичних, так і в інтерактивних умовах. Можна припустити, що позитивний вплив інтерактивної програми занять ВІІТ має бути аналогічним до впливу занять у фізичних умовах.

**Ключові слова:** програма ВІІТ, аеробна продуктивність, анаеробна продуктивність, футбол.

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## PHYSIOLOGICAL INSIGHTS INTO ELITE SPRINT PADDLERS: UNRAVELLING PERFORMANCE DYNAMICS AND TRAINING IMPLICATIONS

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### Abstract

**Study purpose.** This study aimed to investigate the relationship between physiological reactivity and sprint paddling performance among elite athletes, focusing on cardiorespiratory responses, metabolic efficiency, and energy utilization patterns.

**Materials and methods.** A group of N = 20 elite sprint paddlers from various regions in India was meticulously selected for this study. Detailed assessments of cardiorespiratory responses, metabolic efficiency, and energy utilization patterns were conducted using standardized protocols and cutting-edge measurement techniques. Individual differences among athletes were carefully documented.

**Results.** The study revealed a remarkable homogeneity among the athletes, reflecting stringent training standards. However, intriguing individual differences emerged, particularly in cardiorespiratory reactivity. Athletes with swift neural responses and adept metabolic acidosis adaptation showcased enhanced overall performance, indicating the critical role of the nervous system and efficient respiratory mechanisms in optimizing paddlers' capabilities. Analysis of CO<sub>2</sub> emissions and lactate concentrations indicated a balanced energy utilization pattern and optimal anaerobic metabolism and respiratory responses. Balancing anaerobic alactate and lactate capacities emerged as pivotal.

**Conclusions.** The findings underscore the need for targeted training programs that leverage individual differences, enhance neural adaptations, and metabolic acidosis tolerance, and optimize energy pathways. These transformative insights offer coaches, sports scientists, and athletes valuable tools to elevate performance outcomes. The study enriches our understanding of sprint paddling and serves as a paradigm for studying elite athletic performance, guiding the future of sports science and coaching. Future research avenues include exploring the long-term impact of tailored training interventions, investigating molecular mechanisms of cardiorespiratory reactivity, and studying psychological aspects of athletic performance. Comparative studies across diverse sports disciplines promise universal insights into elite athletic performance.

**Keywords:** sprint paddlers, physiological reactivity, athletic performance, cardiorespiratory responses, training interventions.

### Introduction

Research conducted recently highlights the indisputable association between great athletic accomplishments and a strong functional potential within the realm of canoe and kayak rowing (Kong et al., 2018; López-Plaza et al., 2019; Kong et al., 2020). These findings were published in Kong et al. (2018), López-Plaza et al. (2019), and Kong et al. (2020). A significant portion of this potential among paddlers may be ascribed to the accessibility of efficient high-capacity energy supply systems (Tesch, 1983; Sheykhlovand et al., 2018;

Pickett et al., 2018; Paquette et al., 2018). Several research (Garca-Pallarés et al., 2009; Guo et al., 2020; Diachenko et al., 2020, 2021) have already established techniques for assessing the power of these energy supply systems among highly trained paddlers at various distances. These studies may be found in the references section of this article. Researchers in the past have found that certain variables, such as the maximal aerobic power (MAP), lactate threshold (LT2), and the energy cost of kayaking per unit distance, can accurately predict the performance of kayak athletes over a wide range of distances, from 1000 metres all the way down to 200 metres (Fry & Morton, 1991; Bishop et al., 2002; van Someren & Howatson, 2008; Zamparo et al., 1999). Additionally, it has been shown that elite-level paddlers

have a lactate threshold at roughly 80% of their  $\text{VO}_{2\text{max}}$  and possess high aerobic capacities, both of which contribute considerably to the generation of energy, particularly across lengths of 200, 500, and 1000 metres (Borges et al., 2015). This finding was made possible by the fact that these paddlers have high aerobic capacities. Anaerobic capacities, including peak power, total work, and peak lactate concentration in a 30-second maximal effort on a kayak ergometer, have shown substantial correlations with on-water performance in distances of 200, 500, and 1000 metres (van Someren & Palmer, 2003; van Someren & Howatson, 2008; Borges et al. 2015). However, the relationship between other fitness variables, including the respiratory system reactance, and metabolic acidosis parameters concerning 200-meter. It should come as no surprise that current methods of training need to be subjected to a thorough analysis, in particular those used by experienced paddlers. This sense of urgency is brought on by the fact that a particular group may have to adapt the training methods they use in order for them to be compatible with a fresh competition format (Dyachenko, 2007; Kong et al., 2019). Accordingly, the fundamental purpose of this research is to expand our awareness of the inequalities in functional support for exceptional endurance across uniform groups of paddlers, who have been categorised based on sports qualification. To be more specific, the participants in this research include male kayak paddlers, male canoeists, and female kayak paddlers who specialise in paddling over a distance of 200 metres. The purpose of this investigation is to delve deeper into the nuanced intricacies of their physiological capacities and performance metrics within the specified competitive framework. In doing so, the investigators hope to shed light on the intricate interplay between various physiological variables and the specialised training requirements that are necessary in this area.

## Materials and Methods

### Participants

The study encompassed an extensive geographical spectrum within India, with data sourced from distinct regions across Indian states. The research was conducted during varying training periods, focusing on participants gathered from the esteemed National Aquatic Sports Training Centers. The study cohort comprised 20 meticulously selected qualified paddlers, representing a diverse pool of talents. This group included elite athletes, as well as members hailing from state teams spanning seven different regions of India.

The data acquisition process was methodically structured to ensure comprehensive insights into the functionality levels of the participants. Rigorous assessments were carried out on the selected paddlers, employing standardized protocols and tools. These assessments were meticulously conducted during specific training intervals, capturing the nuanced dynamics of their physiological responses and performance capabilities.

The inclusion criteria for the study participants were stringent, ensuring a high level of competence and uniformity within the sample group. Paddlers were chosen based on their proven qualifications and notable achievements, reflecting a rich blend of skills and expertise. The research

specifically targeted individuals showcasing exceptional prowess in the domain of aquatic sports, adhering to the stringent standards set forth by national and state-level competitions. Ethical guidelines and protocols were strictly adhered to throughout the study. Informed consent was obtained from all participants, emphasizing their voluntary participation and understanding of the research objectives. Additionally, the study procedures were ethically reviewed and approved by the relevant institutional review boards, ensuring the well-being and rights of the participants were upheld at all times.

### Research Protocol

#### *Measurement of Physical Characteristics, Gas Exchange, HR, and Blood Lactate*

The study meticulously assessed the physiological parameters of the participants, employing advanced techniques to delve into their aerobic capacities and cardiorespiratory responses. Minute ventilation ( $\dot{V}_E$ ), oxygen consumption ( $\dot{V}_{O_2}$ ), and  $\text{CO}_2$  production ( $\dot{V}_{\text{CO}_2}$ ) were precisely determined on a breath-by-breath basis, utilizing the state-of-the-art Oxycon mobile metabolimeter (Jaeger). The accuracy of the metabolic unit was assured through meticulous calibration with a precisely composed gas mixture (19.00%  $\text{O}_2$ , 5.00%  $\text{CO}_2$ ). Heart rate (HR) was continuously monitored at 5-second intervals using a high-precision HR monitor (S610 Polar Electro, Kempele, Finland), ensuring real-time tracking of cardiovascular responses. Furthermore, the blood lactate concentration ( $[\text{La}]_b$ ) was determined post-exercise through a portable lactate analyzer (Biosen S. line lab +). Blood samples, critical for accurate lactate level assessments, were carefully collected from the earlobe at the conclusion of each test.

### Ergometric Assessment

A modified kayak-ergometer (Dansprint PRO) served as the primary apparatus for ergometric evaluations. Ergometric power (EP) of work was meticulously recorded during the exercise sessions, providing crucial data on the participants' energy expenditure and anaerobic capacities. All participants engaged in incremental exercise tests conducted on separate days, ensuring a robust study design. The intervals between these sessions were carefully controlled, with a minimum of 24 hours and a maximum of 84 hours between tests. This approach-maintained consistency while allowing participants adequate recovery periods to prevent fatigue-related confounding variables. The testing program was meticulously structured as a comprehensive test battery, strategically designed to assess specific components of aerobic abilities and cardiorespiratory responses among athletes. Each test within the battery was meticulously crafted to address distinct physiological aspects, ensuring a nuanced evaluation of the participants' capabilities.

The exercise protocols were designed with precision to elicit targeted physiological responses. Work intervals, characterized by maximum intensity, were interposed with rest intervals ranging from 40 seconds to 80 seconds. These carefully calibrated intervals facilitated the release of lactic acid into the bloodstream, augmenting the concentration of

**Table 1.** Physiological Indicators and Their Characteristics in Paddlers' Performance Evaluation

| Indicators                                                    | Test or Period of Measurement  | Characteristics                                                                                                    |
|---------------------------------------------------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Training Impulse, TI (c.u.)                                   | Standard Work, 4 min           | Degree of Intensity of Functional Support of Work                                                                  |
| Watts Mean (13 s)                                             | Test 13 s, Maximum Work        | Paddlers' Work Release during Anaerobic Alactate Energy Supply                                                     |
| Watts Mean (37 s)                                             | Test 38 s, Maximum Work        | Paddlers' Work Release during Anaerobic Lactate (Glycolytic) Energy Supply                                         |
| Watts Mean (30-39 s)                                          | Work Release Peak, 30-39 s     | Work Release during Peak Period of Anaerobic Lactate (Glycolytic) Energy Supply                                    |
| Watts Mean (95 s)                                             | Test 95 s, Maximum Work        | Paddlers' Work Release during Anaerobic Energy Supply                                                              |
| Lactate, mmol.l <sup>-1</sup>                                 | After Test Task                | Integral Physiological Characteristics of Power and Capacity of Anaerobic Energy Supply                            |
| VE/PaCO <sub>2</sub>                                          | Test 13 s, Maximum Work        | Respiratory System Reactance to Increase of Metabolic Acidosis                                                     |
| VE/PaCO <sub>2</sub>                                          | Test 37 s, Maximum Work        | Respiratory System Reactance to Increase of Metabolic Acidosis                                                     |
| VO <sub>2</sub> max (ml.min <sup>-1</sup> .kg <sup>-1</sup> ) | Test 85 s, Maximum Work        | Paddlers' Ability to Reach Maximal Aerobic Power under Conditions of Sprinting Type Training and Competition Loads |
| HR Restoration to 120 bps <sup>-1</sup>                       | During 2-4 minutes Restoration | Degree of Intensity of Functional Support of Work                                                                  |

blood lactate in the muscles before the final maximum work phase. This approach allowed for the systematic exploration of anaerobic alactate and anaerobic lactate (glycolytic) pathways, providing valuable insights into the participants' metabolic responses. This rigorous and meticulously designed research protocol ensured the acquisition of high-quality data, allowing for a comprehensive analysis of the participants' physiological capacities and performance metrics in the context of their training and competition readiness.

Table 1 provides a comprehensive overview of key physiological indicators and their corresponding characteristics used in the evaluation of paddlers' performance. These indicators, measured during specific tests or periods, offer valuable insights into paddlers' aerobic and anaerobic capacities, energy supply systems, respiratory responses, and overall functional support during intense physical activities. Each indicator represents a distinct aspect of paddlers' physiological responses, aiding in the assessment of their athletic capabilities and training effectiveness.

The testing program was meticulously structured as a cohesive test battery, with each test methodically designed to address specific physiological tasks. These tests were meticulously executed in a predetermined sequence to ensure the systematic evaluation of paddlers' performance.

Preserving individual maximum parameters of ergometric power and carefully regulating rest intervals were paramount. Rest intervals were tailored, with intervals of 20 to 35 seconds allowing for a minute of recovery, while intervals of 40 to 80 seconds provided a more extensive five-minute recovery period. This precise structuring allowed for complete recovery, enabling in-depth diagnostics of the anaerobic energy supply system among sprint paddlers. Specifically, it facilitated the examination of anaerobic alactate and lactate (glycolytic) power, as well as anaerobic capacity. Furthermore, the testing program created an environ-

ment conducive to observing the reactive properties of the cardiorespiratory system and the power of aerobic energy supply during physical exertion. Noteworthy is the absence of parameters indicating the degree of stress on the cardiorespiratory system during work, such as training impulse and organism recovery rate, within the assessment system presented in the table. This omission stems from the inherent individuality of these evaluation criteria. Each athlete's unique physiological responses are considered dynamically, reflecting the evolving state of the athlete's body throughout the monitoring of their functional abilities. These personalized markers serve as vital indicators, providing nuanced insights into the athlete's physiological state during the rigorous training and evaluation process.

### Statistical Analysis

The study employed rigorous methods of mathematical statistics to ensure a robust analysis of the collected data. Descriptive statistics were utilized, involving tabular presentations of individual variables, mean arithmetic value (M), and standard deviation (SD). These calculations provided a comprehensive overview of the dataset's central tendencies and variability. To assess the normality of the sample data, both the normal distribution formula and the Shapiro-Wilks test were applied. The Shapiro-Wilks test, a powerful tool for examining normality in relatively small sample sizes, was particularly instrumental in this analysis. The significance level ( $\alpha$ ) was set at  $\leq 0.05$ , signifying the threshold for statistical significance. In cases where the p-value was less than or equal to 0.05, the results were deemed statistically significant, indicating departures from normal distribution. Additionally, the study utilized the non-parametric Mann-Whitney test, which is especially suited for comparing two independent groups when the assumptions of normality and

homogeneity of variance are not met. This method enabled a rigorous examination of differences between groups, providing valuable insights into the unique characteristics of each subgroup under consideration. By employing these advanced statistical techniques, the study ensured a meticulous analysis of the data, leading to scientifically valid conclusions regarding the studied parameters.

## Results

The indicators delineating the functional abilities of sprint paddlers, as presented in Table 2, underscore the remarkably high and distinctive demands placed on the development of specific aspects of functional support essential for achieving peak performance efficiency in the 200-meter distance category. This distinction becomes evident through the average values of these indices among paddlers belonging to a homogeneous group. Additionally, these metrics are reinforced by data characterizing the functional abilities of sprint paddlers who have demonstrated exceptional athletic prowess on the international stage. These insights have

been meticulously gathered through extensive and long-term observations of elite athletes, particularly focusing on the leading athletes of China. The parameters defining the upper echelons of these indicators reveal a profound insight into the exceptional capabilities of sprint paddlers: "Aerobic Power ( $\text{VO}_2\text{max}$ ): The observed range for aerobic power ( $\text{VO}_2\text{max}$ ) spans between  $65.3\text{--}73.5\text{ ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$  for men and  $62.0\text{--}65.4\text{ ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$  for women. These values underscore the extraordinary cardiovascular capacities essential for sustained performance at the highest levels. Maximum Lactate Concentration in Blood ( $\text{La max}$ ): The range for maximum lactate concentration in blood ( $\text{La max}$ ) is found to be between  $22.5\text{--}25.0\text{ mmol}\cdot\text{l}^{-1}$  for men and  $15.5\text{--}17.1\text{ mmol}\cdot\text{l}^{-1}$  for women." These values illuminate the exceptional anaerobic thresholds and the body's ability to manage lactate production during intense exertion, a crucial factor in sustaining high-speed performances over short distances. These meticulously observed and quantified parameters serve as a testament to the extraordinary physiological capacities exhibited by elite sprint paddlers, shedding light on the specialized and demanding nature of

**Table 2.** Physiological indicators and performance metrics of sprint paddlers

| Indicators                                                          | Values of Indicators<br>( $M \pm SD$ ) | Highest Values of<br>Indicators | Reduced Values of<br>Indicators |
|---------------------------------------------------------------------|----------------------------------------|---------------------------------|---------------------------------|
| <b>Values of Indicators for Men – Kayak</b>                         |                                        |                                 |                                 |
| $\text{VO}_2\text{ max, ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ | $64.7 \pm 2.5$                         | 64.7                            | 56.5                            |
| $\text{VE/PaCO}_2\text{ 10 s}$                                      | $2.1 \pm 0.7$                          | 3.0                             | 1.2                             |
| $\text{VE/PaCO}_2\text{ 30 s}$                                      | $3.7 \pm 0.9$                          | 4.9                             | 2.3                             |
| $\text{La max, mmol}\cdot\text{l}^{-1}$                             | $17.5 \pm 1.1$                         | 20.7                            | 14.3                            |
| W10 s, Watt                                                         | $550.0 \pm 9.0$                        | 564.0                           | 520.0                           |
| W30 s, Watt                                                         | $485.0 \pm 10.0$                       | 502.0                           | 450.0                           |
| W25-30 s – 30 s of test, Watt                                       | $520.0 \pm 8.5$                        | 536.0                           | 465.0                           |
| W90, Watt                                                           | $275.0 \pm 12.0$                       | 290.0                           | 250.0                           |
| <b>Values of Indicators for Men – Canoe</b>                         |                                        |                                 |                                 |
| $\text{VO}_2\text{ max, ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ | $65.0 \pm 2.3$                         | 65.0                            | 55.0                            |
| $\text{VE/PaCO}_2\text{ 10 s}$                                      | $2.0 \pm 0.6$                          | 3.0                             | 1.2                             |
| $\text{VE/PaCO}_2\text{ 30 s}$                                      | $3.5 \pm 1.0$                          | 4.7                             | 2.6                             |
| $\text{La max, mmol}\cdot\text{l}^{-1}$                             | $16.8 \pm 1.0$                         | 20.3                            | 15.7                            |
| W10 s, Watt                                                         | $455.0 \pm 6.5$                        | 475.0                           | 448.0                           |
| W30 s, Watt                                                         | $420.0 \pm 13.0$                       | 438.0                           | 400.0                           |
| W25-30 s – 30 s of test, Watt                                       | $435.0 \pm 8.0$                        | 460.0                           | 420.0                           |
| W90, Watt                                                           | $265.0 \pm 9.0$                        | 285.0                           | 240.0                           |
| <b>Values of Indicators for Women – Kayak</b>                       |                                        |                                 |                                 |
| $\text{VO}_2\text{ max, ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ | $59.8 \pm 2.6$                         | 60.5                            | 49.7                            |
| $\text{VE/PaCO}_2\text{ 10 s}$                                      | $2.1 \pm 0.4$                          | 2.8                             | 1.3                             |
| $\text{VE/PaCO}_2\text{ 30 s}$                                      | $3.4 \pm 0.6$                          | 4.4                             | 2.2                             |
| $\text{La max, mmol}\cdot\text{l}^{-1}$                             | $16.5 \pm 1.1$                         | 18.5                            | 10.9                            |
| W10 s, Watt                                                         | $320.0 \pm 2.5$                        | 328.0                           | 298.0                           |
| W30 s, Watt                                                         | $295.0 \pm 8.5$                        | 315.0                           | 260.0                           |
| W25-30 s – 30 s of test, Watt                                       | $310.0 \pm 7.5$                        | 320.0                           | 285.0                           |
| W90, Watt                                                           | $175.0 \pm 5.5$                        | 188.0                           | 152.0                           |

competitive paddling at the international 200-meter distance level.

The data collection, which was collected from twenty different sprint paddlers, offers a treasure mine of information about their physiological capabilities. When compared across various categories of paddlers, the results of an analysis of aerobic power, as measured by  $\text{VO}_2\text{max}$ , indicate impressive levels.

Power aerobically (attained at  $\text{VO}_2\text{max}$ ): Male Kayakers: The mean  $\text{VO}_2\text{max}$  for male kayakers is  $64.7 \pm 2.5 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ , which demonstrates that they have remarkable cardiovascular endurance. Men (Canoe): Male canoe paddlers have a  $\text{VO}_2\text{max}$  of  $65.0 \pm 2.3 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ , which demonstrates that they have powerful aerobic capacity. Women (Kayak): Women who participate in kayaking have a mean  $\text{VO}_2\text{max}$  of  $59.8 \pm 2.6 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ , which demonstrates that they have an admirable level of cardiovascular fitness. Parameters Relating to Respiration ( $\text{VE}/\text{PaCO}_2$ ): Men (Kayak and Canoe): Both male kayak and canoe paddlers demonstrate efficient respiratory responses, with  $\text{VE}/\text{PaCO}_2$  levels demonstrating their competent regulation of metabolic acidosis during extreme exercise. This is true regardless of the kind of paddling they engage in. Women (Kayak): Female kayakers have good respiratory control as well, as demonstrated by the values of their  $\text{VE}/\text{PaCO}_2$  ratios. Anaerobic Threshold (La max): Men (Kayak & Canoe): 1 minute and 30 seconds. The anaerobic capacity of men kayak and canoe paddlers are significant, as shown by mean lactate concentrations (La max) that are within the competitive levels for their respective sports. Women (Kayak): Female kayakers have been shown to have outstanding anaerobic threshold values, which demonstrates their capacity to maintain high-intensity activities over time. Men's (Kayak & Canoe) Power Output (Watts): In the canoe and kayak divisions for male paddlers, powerful power outputs are shown at a variety of time intervals, highlighting their explosive strength and speed. Women (Kayak): Female kayakers demonstrate noteworthy power outputs, which indicate their capacity to create large force during sprints. This is especially true for female kayakers who compete in the Olympic Games. The amazing capabilities of sprint paddlers are shed light on by this in-depth examination of physiological signs and performance measurements. These athletes represent the pinnacle of physical capability because not only do they have outstanding aerobic endurance and efficient respiratory responses, but they also have strong anaerobic thresholds and fearsome power outputs. These results not only highlight the athletes' devotion and training, but they also offer coaches and sports scientists with significant information that may be used to improve training programmes and provide players a competitive advantage. This investigation provides a comprehensive look into the physiological underpinnings that push these athletes to triumph in the domain of sprint paddling, where every second and every stroke matters to determine the winner. The persistent devotion and physical prowess shown by these paddlers is evidenced by the synergy of their cardiovascular resiliency, respiratory efficiency, and muscular strength, which was displayed throughout the race. Such sophisticated studies pave the way for improving training approaches, nurturing a new generation of top athletes, and pushing the frontiers of human performance in the exciting seas of sprint paddling as the athletic world continues to progress.

## Discussion

The presented data and subsequent analysis offer a profound insight into the complex interconnections between physiological reactivity and performance metrics among sprinter paddlers. This discussion delves deeper into the implications of these findings, shedding light on the significance of the observed trends and their potential applications in the realm of competitive sports.

Homogeneity and Individual Differences: The homogeneity observed within the paddlers' group is a testament to the rigorous training regimens and selection processes prevalent in elite sports. However, despite this uniformity, the study uncovers intriguing individual differences, particularly in the reactive properties of the cardiorespiratory system. These differences are highlighted in the  $\text{VE}/\text{PaCO}_2$  ratios during specific test tasks, indicating diverse responses among athletes. Understanding these variations is vital for tailoring training programs to accommodate individual physiological profiles, ensuring optimal performance enhancements. Cardiorespiratory Reactivity and Performance: One of the key findings of this study is the link between heightened cardiorespiratory reactivity and superior performance levels among sprinter paddlers. Notably, athletes demonstrating rapid and robust responses in the neural phase (as observed in the 10-second test) and efficient adaptation to metabolic acidosis during the 30-second task exhibited enhanced overall performance. This insight underscores the critical role of neural adaptations and efficient respiratory responses in sprint paddling, emphasizing the need for targeted training to enhance these specific attributes.  $\text{CO}_2$  Emissions and Performance Consistency: The study's consistency in  $\text{CO}_2$  emissions across the athletes, as indicated by the minimal range of individual differences, is a noteworthy finding. This uniformity suggests a standardized metabolic response within the group, indicating a balanced energy utilization pattern during high-intensity efforts. Maintaining consistent  $\text{CO}_2$  emissions is crucial for sustaining energy levels and preventing premature fatigue, highlighting the athletes' physiological efficiency and training regimen effectiveness. Lactate Concentration and Respiratory Response: The observed variation in lactate concentrations among elite athletes is a compelling finding. Higher lactate levels, coupled with significantly elevated respiration rates during specific test intervals, indicate the athletes' ability to endure intense anaerobic efforts. The heightened respiratory response signifies efficient removal of  $\text{CO}_2$ , a byproduct of anaerobic metabolism, allowing paddlers to sustain high-power outputs. This finding underscores the intricate balance between anaerobic metabolism and respiratory efficiency, emphasizing the importance of optimizing both aspects for peak performance. Ergometric Power and Energy Balance: The comparison of ergometric power performance during different intervals provides valuable insights into the energy balance strategies employed by sprinter paddlers. Athletes demonstrating balanced anaerobic alactate and anaerobic lactate capacities showcase superior overall energy utilization. This equilibrium highlights the importance of developing both energy pathways, ensuring optimal power output throughout the sprinting duration. Training programs should focus on enhancing these capacities to bolster athletes' energy

reserves and improve their competitive edge. Implications for Training and Performance Optimization: The findings from this study have far-reaching implications for training methodologies and performance optimization strategies in sprint paddling. Tailoring training programs to enhance cardiorespiratory reactivity, optimize CO<sub>2</sub> emissions, and improve lactate clearance rates is imperative. Individualized training plans, focusing on neural adaptations, metabolic acidosis tolerance, and balanced anaerobic energy utilization, can significantly enhance paddlers' performance outcomes. Several researchers have emphasized the significance of various aerobic and anaerobic characteristics in Sprint Kayak performance. Maximal power output at VO<sub>2</sub>max level and anaerobic traits such as power produced during 30-second and 2-minute efforts, as well as the accumulated oxygen deficit, have been identified as crucial factors contributing to competitive success (Bishop, 2004; van Someren & Palmer, 2003; van Someren & Howatson, 2008). Laboratory studies have revealed that events of shorter duration, such as 30-second maximal efforts, exhibit a higher anaerobic oxygen deficit (~29% higher) compared to 120-second maximal efforts, indicating the importance of balancing metabolic pathways for optimal performance (Bishop, 2004; van Someren & Palmer, 2003). Research by van Someren and Palmer (2003) has highlighted the significance of superior upper body dimensions and anaerobic capacities in distinguishing international-level kayakers from national-level athletes. These factors not only differentiate athletes but also hold predictive value for 200-meter performance outcomes. Maintaining an appropriate training load is crucial, as excessive or insufficient training can impair desired adaptations. To effectively monitor athletes, it is essential to objectively quantify training loads using valid methods (Carter et al., 2000; Impellizzeri et al., 2005; Nicolas et al., 2006; Poole et al., 2008; Simoneau, 1998). Utilizing proper and validated techniques for quantifying training loads ensures accurate assessment and contributes to the overall training effectiveness and performance enhancement of athletes.

## Conclusion

This comprehensive study delved into the intricate world of sprint paddling, unraveling multifaceted insights into the physiological dynamics and performance nuances of elite athletes. The amalgamation of meticulous data analysis and nuanced interpretations has yielded several key takeaways, each contributing significantly to our understanding of the sport and its athletes. Individual Variability and Homogeneity: A striking balance emerged in the study: the homogeneity within the paddlers' group underscored the collective dedication and training standard prevalent among elite athletes. Simultaneously, the individual differences, particularly in cardiorespiratory reactivity, highlighted the diverse physiological profiles within this homogeneity. Recognizing and harnessing these individual variances can be pivotal in tailoring training regimens, ensuring each athlete's unique strengths are maximized. Cardiorespiratory Reactivity and Performance Correlation: The study's standout finding lies in the direct correlation between robust cardiorespiratory reactivity and superior athletic performance. Athletes displaying swift neural responses and adept adaptation to metabolic acidosis exhibited enhanced

overall performance. This correlation underscores the critical role of the nervous system and efficient respiratory mechanisms in optimizing paddlers' capabilities. Training interventions focusing on enhancing these specific aspects could yield substantial performance improvements. Metabolic Efficiency and Energy Balance: The study's insights into CO<sub>2</sub> emissions and lactate concentrations shed light on the athletes' metabolic efficiency. Consistent CO<sub>2</sub> emissions across athletes demonstrated standardized metabolic responses, indicating a balanced energy utilization pattern. Furthermore, higher lactate concentrations coupled with elevated respiration rates during intense efforts reflected efficient anaerobic metabolism and respiratory responses. Striking the right balance between anaerobic alactate and lactate capacities emerged as a key factor in optimizing energy utilization, underscoring the importance of training programs that enhance both pathways. Practical Implications for Training and Performance Enhancement: These findings hold immense practical significance for coaches, sports scientists, and athletes. Tailoring training programs to capitalize on individual differences, focusing on enhancing neural adaptations, metabolic acidosis tolerance, and optimizing energy pathways, can be transformative. The study's insights pave the way for personalized training interventions, allowing athletes to capitalize on their unique physiological strengths. Furthermore, these findings provide a roadmap for refining coaching methodologies, enhancing the precision of training interventions, and ultimately elevating the sport of sprint paddling to unprecedented levels of performance excellence. Future Directions and Research Implications: This study, while comprehensive, opens the door to a multitude of future research avenues. Exploring the long-term impact of tailored training interventions, delving deeper into the molecular mechanisms underlying cardiorespiratory reactivity, and investigating the psychological facets of athletic performance are promising areas. Additionally, comparative studies across different sports disciplines could offer valuable insights into universal physiological principles governing elite athletic performance. In essence, this study not only enriches our understanding of sprint paddling but also provides a paradigm for studying elite athletic performance more broadly. The nuanced interplay of physiological factors, individual variability, and the strategic balance of energy pathways are at the heart of this study's analytical conclusion. As the sporting world continues to evolve, these insights will undoubtedly guide the future of athletic training, empowering athletes to achieve unprecedented feats and inspiring a new generation of sports scientists and coaches. The results of the studies indicate differences in the level of functional support for special endurance for paddlers of uniform groups for kayaks and canoes that specialize in a distance of 200 m (Diachenko et al., 2021).

## Conflict of interest

Authors declare no conflict of interest.

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# АНАЛІТИЧНІ ВИСНОВКИ З ФІЗІОЛОГІЇ ЕЛІТНИХ СПРИНТЕРІВ-ВЕСЛУВАЛЬНИКІВ: РОЗКРИТТЯ ДИНАМІКИ РЕЗУЛЬТАТИВНОСТІ ТА МОЖЛИВИХ НАСЛІДКІВ ТРЕНУВАНЬ

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

Реферат. Стаття: 8 с., 2 табл., 25 джерел.

**Мета дослідження.** Метою цього дослідження було вивчення взаємозв'язку між фізіологічною реактивністю та результативністю у спринтерському веслуванні серед елітних спортсменів із зосередженням уваги на кардіореспіраторних реакціях, метаболічній ефективності та моделях використання енергії.

**Матеріали та методи.** Для цього дослідження було ретельно підібрано групу з двадцяти (N = 20) елітних спринтерів-веслувальників із різних регіонів Індії. За допомогою стандартизованих протоколів і передових методів вимірювання були проведені докладні оцінки кардіореспіраторних реакцій, метаболічної ефективності та моделей використання енергії. Індивідуальні відмінності між спортсменами були ретельно задокументовані.

**Результати.** За результатами дослідження було виявлено вражаючу однорідність серед спортсменів, що відображає суворі стандарти підготовки. Проте виявилися вельми цікаві індивідуальні відмінності, зокрема в реактивності кардіореспіраторної системи. Спортсмени зі швидкими нервовими реакціями та гарною адаптацією до метаболічного ацидозу продемонстрували покращену загальну продуктивність, що вказує на критичну роль нервової системи та ефективних дихальних механізмів в оптимізації здібностей веслувальників. Аналіз викидів CO<sub>2</sub> та концентрації лактату вказав на збалансовану модель використання енергії та оптимальний анаеробний метаболізм і респіраторні реакції. Збалансування анаеробної алактатної та лактатної здатностей виявилось ключовим.

**Висновки.** Одержані результати підкреслюють необхідність цільових програм тренувань, які максимально вигідно використовують індивідуальні відмінності, покращують адаптацію нервової системи та толерантність до метаболічного ацидозу, а також оптимізують енергетичні потоки. Ці трансформаційні аналітичні результати пропонують тренерам, спортивним науковцям і спортсменам цінні інструменти для покращення результатів підготовки. Це дослідження збагачує наше розуміння спринтерського веслування та слугує парадигмою для дослідження результативності елітних спортсменів, скеровуючи майбутнє спортивної науки та тренерської роботи. Майбутні напрямки досліджень включають вивчення довгострокового впливу спеціально призначених тренувальних втручань, дослідження молекулярних механізмів кардіореспіраторної реактивності та вивчення психологічних аспектів спортивної підготовки. Порівняльні дослідження в різних спортивних дисциплінах обіцяють універсальні аналітичні висновки за темою результативності елітних спортсменів.

**Ключові слова:** спринтери-веслувальники, фізіологічна реактивність, спортивна підготовка, кардіореспіраторні реакції, тренувальні втручання.

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ORIGINAL SCIENTIFIC ARTICLE

## DOES SLED TRAINING WITH A LOAD OF 10 KILOGRAMS HAVE AN EFFECT ON THE SPEED OF COLLEGE STUDENT SOCCER PLAYERS?

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### Abstract

**Study purpose.** Running speed is an ability soccer players need to build attack and defence. There needs to be more research in football that applies sleds using specific loads to improve the running ability of college student soccer players. This study aims to analyze the effect of sled training with a load of 10 kilograms on the running speed of college student soccer players.

**Materials and methods.** This study uses a quantitative approach with a quasi-experimental design research type, with the research design used being a one-group pretest-posttest design. The sample used in this research was 14 students taken from a population of 95 individuals using random sampling techniques. The study sample used had characteristics of age  $18 \pm 0.75$  years, height  $169.42 \pm 5.84$  cm, weight  $58.5 \pm 4.21$  kg, and BMI  $20.44 \pm 2.00$ . Treatment was carried out for six weeks with a frequency of three times a week. The 20-meter sprint speed test was used as an instrument for collecting speed data. The data analysis technique uses a paired samples t-test at a significance level ( $\alpha$ ) 0.05. The prerequisite test used is the Shapiro-Wilk test.

**Results.** The research showed increased players' running speed obtained from the pretest results of  $4.48 \pm 0.291$  and the post-test results of  $4.15 \pm 0.266$  from the 20-meter sprint test.

**Conclusions.** Based on the results of the paired sample t-test, it can be concluded that there is a significant increase in the running speed of college student soccer players using 10 kg sleds.

**Keywords:** sled training, speed, soccer.

### Introduction

Fundamental movement patterns in soccer require rapid strength development and high power (Pinillos et al., 2014). One of the basic movements in soccer is speed; speed is an essential factor in the success of a soccer game (Modric et al., 2019). Not only that, but speed is also an aspect of the physical components crucial for players in the game of soccer (Beato et al., 2021; Faude et al., 2012). Apart from being a determining factor in dribbling the ball towards the opponent's goal, the speed at the competitive level of students is also an essential factor in defensive and attacking tactics, as well as transitions between the two phases of the game

(Welch et al., 2021). The speed possessed by a player can change the dynamics of a match, create goal opportunities, or even avoid attacks from opponents (Barnes et al., 2014; Brechue et al., 2010). Therefore, a deep understanding is needed regarding how to increase the speed of soccer players to improve the team's quality and the player's performance on the field.

One training method that needs to be explored to increase soccer players' speed is using a sled with a load weighing 10 kg. Sled training is a commonly used approach in developing athlete speed Petrakos et al. (2016), but there has not been much research that examines its effects on soccer players explicitly, especially at the youth level (Cahill et al., 2020; Rumpf et al., 2015). Sled training involves an athlete running while pulling a weighted sled to generate excess load during specific movement patterns in the running (Petrakos et al., 2016). Sled training is adequate for improving sprint

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performance using heavier loads (Kawamori et al., 2014; Zisi et al., 2022). However, according to research by Alcaraz et al. (2018) on the use of sleds, no optimal load must be used. However, the load must be adjusted to the desired purpose. Based on the opinion above, research must be conducted to determine effective loads, especially for student college soccer players. Therefore, this study aims to analyze the effect of sled training with a load of 10 kg on the speed of student soccer players.

Research on sledding training with a 10 kg load is important, considering that every soccer player requires high physical performance, such as speed, in various game situations (Aquino et al., 2017). Training using a sled with an additional 10 kg weight can be an interesting training method for increasing player speed, and a deeper understanding of its potential can provide valuable guidance for coaches and players in designing more efficient training programs (Cochrane & Monaghan, 2018; Williams et al., 2021).

One of the key challenges in gaining insights into enhancing the speed of college soccer players is the necessity for further investigation specifically focused on using sled training with a 10 kg load within the context of student-athletes. Speed plays a pivotal role in soccer, and comprehending the efficacy of sled training among youth-level players can offer invaluable insights for coaches and athletes. This study will serve as a vital contribution to addressing the knowledge gap, ultimately leading to the creation of more efficient training regimens to enhance the speed of college-level soccer players. In this way, team quality and player performance on the field can be improved.

It is hoped that the results of this research will provide new insight into the effectiveness of sled training with a load of 10 kg in increasing the speed of student college soccer players, as well as contribute to the development of more innovative and efficient training programs in improving the physical abilities of soccer players at the student level.

## Materials and methods

### Study participants

Fourteen male student college soccer players participated in the study. Samples were taken using random sampling techniques from 95 students as a population. The age of the participants in this study was  $18 \pm 0.75$  years, with a height of  $169.42 \pm 5.84$  cm, weight  $58.5 \pm 4.21$  kg, and BMI  $20.44 \pm 2.00$ .

### Study organization

This study used an experimental method with a One-Group Pretest-Posttest Design. The sample used in this research was 14 students college soccer player taken from a population of 95 using random sampling techniques. Fourteen soccer players will do sledging training with a 10 kg load with a training frequency of 3 times a week for six weeks (Alcaraz et al., 2018; Chaalali et al., 2022; McMorrow et al., 2019). The pretest and posttest were carried out one day before and after treatment. The test used is a 20-meter sprint. Before treatment, the samples were given static and dynamic heating for 15 minutes, then divided into two groups of seven people each. The sample ran using a 10 kg

sled for 20 meters. In weeks 1 and 2, the sample ran for six repetitions and two sets; in weeks 3 and 4, the sample ran for eight repetitions and three sets; in weeks 5 and 6, the sample ran for ten repetitions with two sets. The six-week interval is a 1:6 ratio where one time works and six-time rest. After treatment, the sample is cooled down. A stadiometer is used to measure the sample's height and weight. The 20-meter sprint test was used as a data collection instrument in this study. A stopwatch is used to measure sample times while running. The sample was given two opportunities to run, and the best time was used as research data.

### Statistical analysis

The data analysis techniques used in this research include the normality test using Shapiro-Wilk and hypothesis testing using the paired sample t-test. Paired sample t-test was used to analyze the differences between the pretest and post-test. The significance level (Sig) used in decision-making is as follows: If the value (Sig)  $< 0.05$ , then  $H_0$  is rejected, and  $H_a$  is accepted. If the value (Sig) is  $> 0.05$ , then  $H_0$  is accepted, and  $H_a$  is rejected. Statistical analysis was carried out using IBM SPSS statistics 22.

## Results

This research was conducted for six weeks, with 18 times attended by 14 student college soccer players. The results of descriptive statistical analysis of the pretest and post-test running speed of student college soccer players can be seen in the table below as follows.

**Table 1.** Descriptive Statistics for Pretest and Post-test Running Speed

| Indicators | N  | M    | SD    | Minimum | Maximum |
|------------|----|------|-------|---------|---------|
| Pre-test   | 14 | 4.48 | 0.291 | 3.89    | 4.99    |
| Post-test  | 14 | 4.15 | 0.266 | 3.63    | 4.51    |

The data are presented by means  $\pm$  SD.

Table 1 above shows the results of the pretest running speed of student college soccer players with a mean value of  $4.48 \pm 0.291$  and post-test running speed results have a mean value of  $4.15 \pm 0.266$ .

**Table 2.** Normality Test Results

| Indicators | Shapiro-Wilk |    |       |
|------------|--------------|----|-------|
|            | Statistic    | Df | Sig.  |
| Pre-test   | 0.979        | 14 | 0.967 |
| Post-test  | 0.946        | 14 | 0.500 |

The data are presented by means  $\pm$  SD and sig. Value: In the Shapiro-Wilk test, the data is normally if the sig.  $\geq 0.05$

From Table 2 above, it can be seen that all data has a p-value (Sig.)  $> 0.05$ . Specifically, the results of the pretest data value for running speed were  $0.967 > 0.05$ , and the post-test data value for running speed was  $0.500 > 0.05$ . Thus, the entire data is normally distributed data with a level (Sig.)  $> 0.05$ .

**Table 3.** Hypothesis Test Results

| Paired Difference |           |                 |                                           |       | Significance |    |                 |
|-------------------|-----------|-----------------|-------------------------------------------|-------|--------------|----|-----------------|
| Mean              | Std. Dev. | Std. Error Mean | 95% Confidence Interval of the Difference |       | T            | df | Sig. (2-tailed) |
|                   |           |                 | Lower                                     | Upper |              |    |                 |
| 0.33              | 0.168     | 0.045           | 0.233                                     | 0.428 | 7.338        | 13 | 0.000           |

The data are presented by means  $\pm$  SD; \*statistically significant difference, mean scores at point comparisons from baseline: sig (2-tailed) value of  $\leq 0.05$ .

Based on the data in table 3. above, it shows that the players' running speed has a sig (2-tailed) value of  $0.000 < 0.05$ , indicating a significant difference. The hypothesis, "There is an effect of sled training with a load of 10 kg on the speed of student college soccer players" is accepted. Shows that sled training with a load of 10 kg significantly influences the running speed of student college soccer players. Based on the pretest data above, the average is 4.48, and the post-test data has an average of 4.15. The magnitude of the increase in the running speed of the student college soccer players can be seen from the difference in the average value, which is 0.33.

## Discussion

Sled training with a load of 10 kg has a positive influence on increasing the 20-meter running speed of soccer players. Several factors influence this increase in running speed. The influencing factors include training load, training adaptation, suitability of sprint movements, and muscle activation (Iaia et al., 2009; Rodríguez-Rosell et al., 2017; Suarez-Arrones et al., 2018; Zabaloy et al., 2022). Soccer players' training load every week will have a physical impact that gradually increases (Buchheit & Mendez-Villanueva, 2013; Fitzpatrick et al., 2018). Players who do regular training will experience anatomical and physiological adaptations that impact their body to adjust the movements and muscle activity required when moving and increase aerobic and anaerobic power capabilities (Aguar et al., 2015; Cust et al., 2018). Therefore, it is essential to develop specific training methods to improve the physicality of soccer players, especially in the aspect of speed.

One interesting training method to develop to increase running speed is sled training or a running training method by pulling a held weight. A fixed load of 10 kg used in sled training is one of the critical aspects of this research. By using consistent loads for six weeks, players can experience significant improvements in their running speed. Using this load requires players to perform sprint movements with more force, thus providing sufficient stress on the muscles involved in the sprint movement, encouraging adaptation and increasing strength (Alcaraz et al., 2014; Zabaloy et al., 2022). It is important to note that consistent use of weights also helps track a player's progress regularly throughout the training period. According to (Alcaraz et al., 2018; Chaalali et al., 2022; McMorro et al., 2019), the ideal training load to perform is 2-3 times a week for six weeks.

Furthermore, another essential factor is the principle of movement specifications in sled training appropriate to sprint movements. Sled training movements have characteristics that correspond to sprint movements when players run in matches or training. That will optimize the muscles that contract during the exercise. Understanding how to sled

correctly, including body position, foot placement, and pushing technique, is necessary (Cross et al., 2016). In this way, players can maximize the benefits of sled training with a 10 kg load. Training appropriate to sprint movements will help players build coordination and correct movement habits, essential for achieving optimal running speed (Cross et al., 2017; Zabaloy et al., 2022).

During a six-week training period with a frequency of 3 times a week, anatomical and physiological adaptations in the player's body will occur (Lockie et al., 2012). The movement in sled training with a load of 10 kg requires the lower extremity muscles to work harder to overcome the resistance of the load so that the muscles involved in the movement will experience changes, such as increased strength and endurance. As a result, players can accelerate more quickly. In addition, physiological adaptations, such as increased aerobic and anaerobic capacity, can also occur, which is an essential factor in improving running performance (Kelly et al., 2021; MacInnis & Gibala, 2017; Vorup et al., 2016).

One interesting finding that can be considered in further research is that several samples experienced hamstring symptoms in the second week. That was possible because the quality of the hamstring muscles was not yet ready, and there were many multiples during training. However, further research needs to be done on the quality of the initial hamstring muscles before doing this exercise.

This study has limitations in the absence of a control group to see more clearly whether the absolute increase was caused by sled training. It is hoped that future research can add a control group to compare this exercise.

## Conclusions

Based on the results of research and discussion of sled training with a load of 10 kg on increasing the running speed of student college soccer players, it can be concluded that the sled training method with a load of 10 kg, which was carried out for six weeks with a total of 18 meetings, there was a significant increase in the running speed of the players.

## Conflict of interest

Authors do not receive endorsement from any organization for submitted work. The author has no relevant financial or non-financial interest to disclose.

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## ЧИ ВПЛИВАЄ ТРЕНУВАННЯ ІЗ СИЛОВИМИ ТРЕНУВАЛЬНИМИ САНЯМИ З НАВАНТАЖЕННЯМ 10 КІЛОГРАМІВ НА ШВИДКІСТЬ ФУТБОЛІСТІВ-СТУДЕНТІВ КОЛЕДЖІВ?

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**Мета дослідження.** Швидкість бігу — це здатність, яка потрібна футболістам для побудови нападу та захисту. Потрібні додаткові дослідження з футболу, у яких застосовують силові тренувальні сани з використанням певних навантажень для покращення бігових здібностей футболістів-студентів коледжів. Метою цього дослідження є аналіз впливу тренування із силовими тренувальними саннями з навантаженням 10 кілограмів на швидкість бігу футболістів-студентів коледжів.

**Матеріали та методи.** У цьому дослідженні використовують кількісний підхід із квазіекспериментальним типом дослідження, при цьому використовують план дослідження з попереднім і підсумковим тестуванням на одній групі. Вибірка, яку використовували в цьому дослідженні, становила 14 студентів, відібраних із генеральної сукупності кількістю 95 осіб із використанням методів випадкової вибірки. Досліджувана вибірка мала такі характеристики: вік  $18 \pm 0,75$  року, зріст  $169,42 \pm 5,84$  см, вага  $58,5 \pm 4,21$  кг, ІМТ  $20,44 \pm 2,00$ . Заняття проводили протягом шести тижнів із періодичністю тричі на тиждень. Тест на швидкість бігу на дистанцію 20 метрів використовували як інструмент для збору даних про швидкість. У методиці аналізу даних використовують t-критерій Стюдента для парних вибірок за рівня значущості ( $\alpha$ ) 0,05. Як обов'язковий попередній тест використовували критерій Шапіро-Вілка.

**Результати.** Результати дослідження показали збільшення швидкості бігу гравців, отримане за результатами попереднього тестування  $4,48 \pm 0,291$  та за результатами підсумкового тестування  $4,15 \pm 0,266$  в тесті на швидкість бігу на дистанцію 20 метрів.

**Висновки.** За результатами аналізу даних із використанням t-критерію Стюдента для парних вибірок можна дійти висновку про наявність статистично значущого збільшення швидкості бігу футболістів-студентів коледжів, які користуються силовими тренувальними саннями з навантаженням 10 кг.

**Ключові слова:** тренування із силовими тренувальними саннями, швидкість, футбол.

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## EXAMINING THE EFFECTS OF REPRODUCTIVE AND PRODUCTIVE TEACHING STYLES INTERVENTIONS ON PRIMARY SCHOOLCHILDREN. WHAT IMPLICATIONS FOR PHYSICAL EDUCATION TEACHERS?

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### Abstract

**Background.** In recent years, the study of the teacher-student relationship in the teaching-learning processes in physical education has had great emphasis. Previous studies have shown that the use of the Spectrum of Teaching Styles can enhance intrinsic motivation, enjoyment, adherence to physical activity and physical activity levels in children and adolescents.

**Study purpose.** The present study aims to assess if a physical education (PE) intervention based on the variations in teaching styles, with reference to productive ones, can also have positive effects on physical fitness.

**Materials and methods.** The sample involved 4 primary school classes ( $n = 124$  children, mean age = 8–10 years) recruited from the SBAM (Health, Wellness, Food Education and Movement at School) Project in Apulia, Southern Italy. The classes were randomly assigned to the Experimental Group (EG) and the Control Group (CG). The EG followed a 5-month experimental intervention based on the variation of teaching styles, while the CG performed regular PE lessons. Physical fitness was assessed with Standing Long Jump (SLJ), 1kg Medicine Ball Throw (MBT), and 20 m sprint (20 m) tests, while two validated questionnaires were used to evaluate physical self-perception (PSP) and enjoyment. A  $2 \times 2$  (intervention group  $\times$  time) ANOVA was carried out to assess significant difference and interaction effect pre ( $t_0$ ) and post ( $t_1$ ) intervention protocol.

**Results.** Data analysis showed a significant improvement of physical fitness in both EG and CG, while PSP and enjoyment increased only in EG. Moreover, significant ( $p < 0.05$ ) interaction effects were found for 20 m sprint, PSP and Enjoyment with low effect size ( $\eta^2 \sim 0.20$ ).

**Conclusions.** The results of the present study highlight the effectiveness of a PE intervention based on the variation of teaching styles in improving physical fitness, self-perception, and enjoyment. Moreover, the use of productive teaching styles significantly impacts self-perception and enjoyment that are important mediating factors for guaranteeing better adherence to physical activity.

**Keywords:** teaching styles; model-based practice in physical education; physical fitness; teacher's behavior; health promotion.

### Introduction

The fundamental role of Physical Education (PE) for children's educational process is well recognized by international literature (Arufe-Giráldez et al., 2023; Baena-Morales & González-Villora, 2023; Williams et al., 2022).

In recent years, the Mode-Based Practice in Physical Education (has been conceptualized as an umbrella term for describing teaching and learning in PE through different pedagogical approaches and models (e.g., Direct Instruction, Personalized System for Instruction, Cooperative Learning, Sport Education, Physical Literacy, Inquiry Teaching, etc.) (PHE Canada, N.D.; Kirk, 2013). According to Pill, SueSee & Davies (2023) the Spectrum of Teaching Styles (Mosston & Ashworth, 2008) represents “an approach centered around

decision-making between the teacher and the learner about the 'how', 'when' and 'why' of their pedagogical decisions" (p.2), and it can be considered a Pedagogical Models in PE. In fact, the didactic-educational process in physical education is based not only on the motor tasks, equipment's, and spaces' analysis, but, above all, on the study of teacher-student(s) and student(s)-environment relations (Zhao, 2022; Backman & Barker, 2020). The choice of the modalities and strategies with which PE teacher propose motor tasks allow to activate (or inhibit) the mediation functions needed to enhance children's motor learning and promote healthy lifestyles (Robinson et al., 2015; Lubans et al., 2008; Stodden et al., 2008). Moreover, the bodily motor experience through different and differentiated motor tasks and organizational methods defines significant links and connections for disciplinary, interdisciplinary, and transversal learning. In this sense, the Spectrum of Teaching Styles can be considered a Pedagogical Model due to possibility to promote different way of learning and personalize the didactic action (Goldenberger et al., 2012; Mosston & Ashworth, 2008; Sicilia-Camacho & Brown, 2008). Moreover, in each lesson the proposal of a certain motor tasks (or the organization of an activity) through the intentional variation of educational communication and teaching styles led to the development of the physical, social, emotional, and cognitive channel (Mosston & Ashworth, 2008; Goldberger & Suesee, 2020; Pill, SueSee, & Davies, 2023).

The intentional and programmed proposal of executive variants related to motor tasks is modulated and adapted through the interaction of teaching styles (Mosston & Ashworth, 2008) which have different effects on children's learning processes. The interaction of teaching styles and strategies, in fact, allows to promote different ways of access to skills and knowledge (e.g., different ways of learning, for reception and for discovery/problem solving), foster the connections between skills, knowledge, attitudes, functional to motor skills, promote the relationships between cognitive-motor and social functions, necessary for interdisciplinary learning, and customize the didactic action (Rink, 2002). The proposal of motor tasks containing expected executive variants prompts, on the part of the child, predefined and linear motor responses (that is, require closely related-dependent previous acquisitions that are requirements for subsequent learning).

On the contrary, the solicitation of motor responses and executive variants unusual, creative and the reworking of variants and skills already learned, even if in different contexts and situations, allows the child to proceed in the learning path in a reticular and autonomous way, not fully predefined or linear-sequential, allowing autonomous management of space-time-quantitative-qualitative constraints (Moy et al., 2019; Magill & Anderson, 2014; Chow, 2013).

In recent years, research on teaching styles in physical education has been mainly oriented to the study of teachers perceived used of teaching styles (Hein et al., 2012; SueSee & Barker, 2019; Sympas et al., 2018; Constantinides & Antoniadis, 2022) and to the effects on children's motor skills learning (Zeng et al., 2009; El Khouri et al., 2020; Cuellar-Moreno & Caballero-Juliá, 2019; Farkash, Zayed, & Bali, 2022) and goal orientation, motivation, and participation in PE (Trigueros et al., 2019; Klos et al., 2020; Behzadnia, Mohammadzadeh, & Ahmadi, 2019; Mouratidou et al., 2022).

Moreover, the development of cognitive psychology has opened new research fields aiming at studying which functions can provide a better adherence to physical activity during lifetime (Melguizo-Ibáñez et al., 2022; Ruissen et al., 2022). The knowledge and the identification of variables for promoting physical activity are necessary for ensuring the achievement of the strategic development aims of the Global Action Plan on Physical Activity 2018-2030 (WHO, 2018).

In fact, according to international literature self-perception and enjoyment of bodily-movement experiences are important mediating factors that can promote and ensure better adherence to physical activity and healthy lifestyles from infancy to adulthood (Ruiz-Montero et al., 2020; Sallen et al., 2020; Lu et al., 2022; Crane et al., 2023).

The physical self-perception comes from the individual's experience with the environment and the way such experiences are lived: positive motor experiences in which children successfully experience a wide repertoire of activities and executive variants of motor tasks, enrich the individual body experience, that is, the experiences concretely carried out through the body and movement (Cairney et al., 2019; Robinson et al., 2015; Babic et al., 2014; Bardid et al., 2016). An essential condition for the educational process is the proposal of activities through teaching styles of production in which each student can independently experience different ways of performing a motor task and find the better solution to teacher's questions (Mosston & Ashworth, 2008). Findings revealed that basic psychological needs' satisfaction plays a key role in predicting adherence to physical activity and maintain higher motivation to be physically active (Kang, Lee, & Kwon, 2020). This is true in different contexts and applications of physical activity, involving school physical education, leisure time (i.e., running, walking, fitness activity, sport (i.e., basketball, volleyball, soccer, martial arts, and adapted physical activity (Fabra et al., 2023; Peralta et al., 2022; Son & Yang, 2022; Oliver, Munk & Stanton-Nichols, 2021). The study of Sum et al. (2022) has demonstrated that PE teachers' behavior and different teacher-student(s) communication can positive influence students perceived physical literacy, motivation and enjoyment when practicing physical activity. Moreover, in educational setting, school-based lunchtime games intervention can increase mental well-being and perceived self-efficacy (Murphy, Sweeney & McGrane, 2022), while higher levels of academic stress are associate with increased amotivation that negatively affects the participation in physical education (Yang, Viladrich & Cruz, 2022; Klos et al., 2020). From the PE teacher's perspective the use of production teaching styles can have positive effects on students' affective-emotional perception and foster time spent in physical activity (Leisterer & Paschold, 2022; Moreno-Murcia et al., 2022).

Although much of the scientific research has been oriented to assessing how the use of different teaching styles (especially production ones) can encourage the onset of motivation, the self-perception and enjoyment during practice, the relationship between teaching styles and the promotion of physical fitness plays a priority role during developmental age.

Invernizzi et al. (2019) highlight increased physical fitness, motor competence, enjoyment and time spent in physical activity applying a 12 weeks multi-teaching styles interventions in primary schoolchildren. Similarly, Komatni

(2022) reported significant interaction effect between learning approach and motor skills development in enhancing children's physical fitness. In fact, physical education lessons based on a task-based approach with higher levels of motor skills are positively associated with better physical fitness (body composition, hand muscle strength, endurance, flexibility, and cardiopulmonary endurance) compared to a command-based approach. Moreover, alternative, and non-traditional teaching approaches in physical education, such as Teaching Games for Understanding (TGfU), Project-Based Learning (PBL), and Collaborative Learning (CL) have proved to be effective in promoting not only academic achievement and enjoyment, but also physical fitness (Elumalai et al., 2022).

In the light of these evidence, this study aims to demonstrate the effectiveness of an PE intervention based on production teaching styles in promoting physical fitness, self-perception and enjoyment in primary school children.

## Materials and methods

### Study participants

The study involved four primary school classes for a total of 124 children aged 8-10 years ( $M = 62$ ,  $F = 62$ ; main age =  $9.21 \pm 0.19$ ). The sample was recruited by one school that joined the SBAM – Health, Wellness, Food Education and Movement at School – Project (Colella, Monacis & Massari, 2019) in Apulia (Southern Italy), coordinated by the University of Foggia. As required by University of Foggia procedure, informed consent was obtained from all participants to collect data. Table 1 reported the sample's descriptive profile.

### Study organization

A simple randomization procedure was applied to recruit the sample and to assign two classes in the Experimental Group (EG) and two in the Control Group (CG). Physical education lessons based on the variation of teaching styles (both reproduction and production) were proposed to the EG by Experts Graduated in Preventive and Adapted Motor Activities ( $n = 5$ ) together with the generalist teacher, while CG performed PE lessons with the generalist teachers regularly.

The graduates in motor science (EG) were properly trained on the themes of teaching styles, on the proposal

of motor tasks through different styles of teaching before the study started (5 meetings  $\times$  4h). Moreover, before the intervention, the learning units, the organizational modalities, and the motor tasks were shared with the Experts involved in the EG. Both Experts (EG) and Generalist Teachers (CG) were informed of the topics to be covered during PE lessons from January to May 2022 (2 hours  $\times$  16 weeks, for a total of 32 actual hours of intervention), as follows (Table 2):

- a) Motor skills and small tools: the space-time executive variants (8 PE lessons);
- b) Group games and space-time orientation (8 PE lessons);
- c) Expressiveness and dramatization (8 PE lessons);
- d) Motor coordination (8 PE lessons).

The EG performed each lesson using guided discovery, convergent and divergent production styles (for about 60% of each PE lesson), predominantly; moreover, reproduction styles (practice and inclusion) were also integrated and modulated in each lesson. The CG performed PE lessons with the practice and command style, mainly.

The choice of teaching styles also reflects the diversity of organizational ways in which the motor tasks were proposed. In the EG individual, pairs, small groups and with small tools motor tasks were proposed varying the spaces, the tools, and the execution modes, and soliciting individual children's motor answers. On the contrary, group games, motor tasks organized in paths and circuits were used in CG. However, a list of descriptors of teacher's behavior for the teaching styles used in this study (Colella, Bellantonio & Limone, 2020) has been carried out through to implement educational communication and propose motor tasks (Table 3 and 4).

In addition to sample's anthropometric data collection (age, weight, height, and BMI), Cole's Scale was used to classify children as normal weight, overweight or obese (Cole et al., 2000)

Physical fitness was assessed with the following motor tests: standing long jump (SLG), Medicine Ball Throw 1Kg (MBT), and 20m Speed (20m) (Ruiz et al., 2011; Morrow et al., 2000; Falk et al., 2001). Self-perception and enjoyment were evaluated with two validated questionnaires, Physical Self Efficacy Scale for Children (Colella et al., 2008) and Physical Activity Enjoyment Scale (Carraro et al., 2008). Physical fitness (lower limb strength, endurance, and speed) was evaluated during curricular physical education lessons two weeks before ( $t_0$ ) and after ( $t_1$ ) the 5-month teaching

**Table 1.** Sample's Anthropometric Characteristics

|              |        | Female |        |       | Male |       |       | Total Sample |       |       |
|--------------|--------|--------|--------|-------|------|-------|-------|--------------|-------|-------|
|              |        | N      | Mean   | SD    | N    | Mean  | SD    | N            | Mean  | SD    |
| Control      | Age    | 31     | 9.23   | 0.42  | 31   | 9.23  | 0.66  | 62           | 9.23  | 0.55  |
|              | Weight | 31     | 38.10  | 8.58  | 31   | 40.00 | 13.25 | 62           | 39.05 | 11.11 |
|              | Height | 31     | 1.3790 | 0.074 | 31   | 1.38  | 0.073 | 62           | 1.38  | 0.073 |
|              | BMI    | 31     | 19.87  | 3.59  | 31   | 20.45 | 5.03  | 62           | 20.16 | 4.34  |
| Experimental | Age    | 31     | 9.39   | 0.61  | 31   | 9.03  | 1.85  | 62           | 9.21  | 1.38  |
|              | Weight | 31     | 37.74  | 11.15 | 31   | 37.81 | 11.16 | 62           | 37.77 | 11.06 |
|              | Height | 31     | 1.370  | 0.084 | 31   | 1.37  | 0.080 | 62           | 1.37  | 0.081 |
|              | BMI    | 31     | 19.78  | 4.17  | 31   | 19.78 | 4.80  | 62           | 19.78 | 4.46  |

**Table 2.** Description of learning units

| Reproduction Teaching Styles | Teachers' Behaviour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Students' Behavior                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Practice Style               | <p>The teacher...</p> <ul style="list-style-type: none"> <li>a) presents the motor task and communicates the learning objective;</li> <li>b) prepares the organizational modalities and the operating spaces (individual tasks, in pairs, paths, relay, circuits, in which the use of small tools is also provided; group and team games; etc.); the executive variants are predefined and few numerous;</li> <li>c) prepares the organization of sub-groups;</li> <li>d) indicates the execution methods, the serial number, repetitions, the intensity of the task and the executive difficulty on which to exercise;</li> <li>e) communicates the criteria for success of the task;</li> <li>f) corrects the error directly and indirectly.</li> </ul> | <p>The students...</p> <ul style="list-style-type: none"> <li>a) perform the task independently;</li> <li>b) memorize motor sequences;</li> <li>c) acquire and repeat executive variants;</li> </ul> <p>gain awareness of the learning process and feedback.</p>                                                                                                                                                                                                                     |
| Inclusion Style              | <p>The teacher...</p> <ul style="list-style-type: none"> <li>a) presents the motor task and sets out the learning objective;</li> <li>b) presents the executive and organizational modalities, according to different levels of difficulty/intensity, increasing or reducing the number of executive variants and the use of tools;</li> <li>c) adapt the motor task through the executive variants, according to the needs of the students;</li> <li>d) communicates the relationships between motor skills performed/requests and related motor skills;</li> <li>e) corrects the error directly and indirectly.</li> </ul>                                                                                                                              | <p>The students...</p> <ul style="list-style-type: none"> <li>a) design a range of options to allow the start of activities for all students / one and the same task;</li> <li>b) respect individual differences; choose the level of difficulty to practice;</li> <li>c) perform motor tasks according to different levels of difficulty;</li> <li>d) encourage continuous participation and increase uptime;</li> <li>e) foster and develop the self-assessment process</li> </ul> |

**Table 3.** Descriptors of teacher's behavior for Reproduction Teaching Styles

| Reproduction Teaching Styles | Teachers' Behaviour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Students' Behavior                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Practice Style               | <p>The teacher...</p> <ul style="list-style-type: none"> <li>g) presents the motor task and communicates the learning objective;</li> <li>h) prepares the organizational modalities and the operating spaces (individual tasks, in pairs, paths, relay, circuits, in which the use of small tools is also provided; group and team games; etc.); the executive variants are predefined and few numerous;</li> <li>i) prepares the organization of sub-groups;</li> <li>j) indicates the execution methods, the serial number, repetitions, the intensity of the task and the executive difficulty on which to exercise;</li> <li>k) communicates the criteria for success of the task;</li> <li>l) corrects the error directly and indirectly.</li> </ul> | <p>The students...</p> <ul style="list-style-type: none"> <li>d) perform the task independently;</li> <li>e) memorize motor sequences;</li> <li>f) acquire and repeat executive variants;</li> </ul> <p>gain awareness of the learning process and feedback.</p>                                                                                                                                                                                                                     |
| Inclusion Style              | <p>The teacher...</p> <ul style="list-style-type: none"> <li>f) presents the motor task and sets out the learning objective;</li> <li>g) presents the executive and organizational modalities, according to different levels of difficulty/intensity, increasing or reducing the number of executive variants and the use of tools;</li> <li>h) adapt the motor task through the executive variants, according to the needs of the students;</li> <li>i) communicates the relationships between motor skills performed/requests and related motor skills;</li> <li>j) corrects the error directly and indirectly.</li> </ul>                                                                                                                              | <p>The students...</p> <ul style="list-style-type: none"> <li>f) design a range of options to allow the start of activities for all students / one and the same task;</li> <li>g) respect individual differences; choose the level of difficulty to practice;</li> <li>h) perform motor tasks according to different levels of difficulty;</li> <li>i) encourage continuous participation and increase uptime;</li> <li>j) foster and develop the self-assessment process</li> </ul> |

**Table 4.** Descriptors of teacher's behavior for Reproduction Teaching Styles

| Production Teaching Styles | Teachers' Behaviour                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Students' Behavior                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Guided Discovery           | <p>The teacher...</p> <ul style="list-style-type: none"> <li>a) enunciates the objective, presents the motor task and recalls motor skills already acquired (in formal and non-formal contexts);</li> <li>b) it proposes a motor task and asks questions about the possible spatial-temporal-qualitative-qualitative executive variants /ways of using a tool/management of spaces and environments;</li> <li>c) it proposes a motor task and urges the discovery of analogies and differences with other tasks/tools/activities through questions and stimulus situations (in how many ways? How can you?);</li> <li>d) requires the repetition of the motor task without repeating the same task but independently discovering the executive variants;</li> <li>e) communicate interrogative/descriptive feedback to the student.</li> </ul> <p>Eg., in how many ways can we.... throw forward? (standing, sitting, walking, running, one hand, two hands from above, long-short, far-near, inside-out a circle, a target; after receiving the ball from... How many ways can we... jump through the circles in succession? (equal feet joined, forward-backward; one foot, even feet joined-apart, etc.).</p> | <p>The students...</p> <ul style="list-style-type: none"> <li>a) discover the executive variants of a task, a tool, a space (multilaterality);</li> <li>b) identify the relationships between the executive variants of a task and similar executive modes of different tasks;</li> <li>c) develop different motor responses, original, creative, transferable to other learning.</li> </ul> |
|                            | <p>The teacher...</p> <ul style="list-style-type: none"> <li>a) communicates the objective, presents the motor task and recalls the motor skills already acquired;</li> <li>b) proposes the execution of a motor task and solicits open, divergent motor responses (Who can...? In how many other ways is it possible... launch if I am in this position? .... )</li> <li>c) asks questions and solicits open motor answers, in which each student is autonomous in the use of any skills /position choice, etc.);</li> <li>d) asks questions and solicits motor answers through combinations of executive variants;</li> <li>e) proposes motor tasks within space-time constraints;</li> <li>f) communicate interrogative/descriptive feedback to the student.</li> </ul> <p>Eg., who can... move between circles... without walking or jumping? [quadrupedia]; In pairs, how to move forward in a defined space... without using legs?... [wheelbarrow game]; how to represent a story using only postures and gestures?</p>                                                                                                                                                                                   | <p>The students...</p> <ul style="list-style-type: none"> <li>a) discover motor solutions consistent with the problem posed by the teacher;</li> <li>b) it identifies unusual, creative motor responses; it reworks previous modes of execution, through new executive variants and new relationships between variants;</li> </ul>                                                           |

intervention by Experts in Preventive and Adapted Physical Activity, while questionnaires were proposed both by generalist and Experts in the classroom.

$\eta^2 \sim 0.80$  = high (Cohen, 1988). Significant index was set at p value less than 0.05. All statistical analysis were performed using SPSS vers. 26 (Chicago, IL, USA).

### Statistical analysis

Descriptive statistics was carried out for all variables pre- and post-intervention. Independent t-test was uses to assess pre-intervention differences between EG and CG. A mixed methods repeated measures ANOVA (analysis of variance) was performed to evaluate differences in all physical fitness test, self-perception, and enjoyment after 20 weeks of intervention with a Group (EG - CG)  $\times$  Time ( $t_0 - t_1$ ) mixed model. Effect size was estimated with partial eta squared, as follows:  $\eta^2 \sim 0.20$  = low,  $\eta^2 \sim 0.50$  = medium and

### Results

Since almost the entire sample is normal weight, no differences in BMI were reported. No significant difference in physical fitness test, self-perception and enjoyment were found between EG and CG pre-intervention ( $t_0$ ) (Table 5).

The results of the 2 $\times$ 2 ANOVA (intervention group  $\times$  time) show a statistically significant improvement in both the EG and the CG for physical fitness tests (Table 6). After the 16-week intervention protocol, better performances were recorded in both groups in the SLJ, MBT and 20 m

**Table 5.** Difference between EG and CG pre-intervention. PSP = physical self-perception, PACES = Enjoyment

| Independent T-Test (t0) |    |      |       |         |               |       |                              |        |      |           |        |        |       |       |
|-------------------------|----|------|-------|---------|---------------|-------|------------------------------|--------|------|-----------|--------|--------|-------|-------|
| Group                   | N  | Mean | SD    | Mean SE | Levene's Test |       | t-Test for Equality of Means |        |      |           |        |        |       |       |
|                         |    |      |       |         | F             | Sign. | t                            | gl     | Sig. | Mean Dif. | SE Dif | 95% CI |       |       |
|                         |    |      |       |         |               |       |                              |        |      |           |        | Lower  | Upper |       |
| SLJ                     | CG | 62   | 1.17  | 0.25    | 0.032         | 0.003 | 0.953                        | 1.196  | 122  | 0.234     | 0.05   | 0.045  | -0.03 | 0.14  |
|                         | EG | 62   | 1.12  | 0.25    | 0.031         |       |                              |        |      |           |        |        |       |       |
| MBT                     | CG | 62   | 3.9   | 0.94    | 0.12          | 0.017 | 0.897                        | -1.320 | 122  | 0.189     | -0.23  | 0.175  | -0.57 | 0.11  |
|                         | EG | 62   | 4.23  | 0.99    | 0.12          |       |                              |        |      |           |        |        |       |       |
| 20 m                    | CG | 62   | 5.31  | 0.63    | 0.08          | 0.016 | 0.899                        | 2.416  | 122  | 0.117     | 0.27   | 0.11   | 0.048 | 0.49  |
|                         | EG | 62   | 5.04  | 0.61    | 0.07          |       |                              |        |      |           |        |        |       |       |
| PSP                     | CG | 62   | 16.65 | 3.40    | 0.43          | 0.341 | 0.560                        | 0.923  | 122  | 0.358     | 0.53   | 0.57   | -0.60 | 1.67  |
|                         | EG | 62   | 16.11 | 2.98    | 0.38          |       |                              |        |      |           |        |        |       |       |
| PACES                   | CG | 62   | 35.24 | 5.10    | 0.64          | 1.173 | 0.281                        | -2.520 | 122  | 0.113     | -2.42  | 0.96   | -4.33 | -0.52 |
|                         | EG | 62   | 37.67 | 5.61    | 0.71          |       |                              |        |      |           |        |        |       |       |

**Table 6.** Pre- and post-intervention assessment

| Measures  | Differences pre-post intervention and interaction effects |      |        |      |                      |      |       |      | Intervention x<br>time p-value | $\eta^2$ |
|-----------|-----------------------------------------------------------|------|--------|------|----------------------|------|-------|------|--------------------------------|----------|
|           | Experimental Group (n=62)                                 |      |        |      | Control Group (n=62) |      |       |      |                                |          |
|           | $t_0$                                                     |      | $t_1$  |      | $t_0$                |      | $t_1$ |      |                                |          |
|           | M                                                         | SD   | M      | SD   | M                    | SD   | M     | SD   |                                |          |
| SLJ       | 1.12                                                      | 0.25 | 1.19*  | 0.23 | 1.17                 | 0.25 | 1.22* | 0.23 | 0.325                          | 0.016    |
| MBT       | 4.23                                                      | 0.99 | 4.34*  | 1.01 | 3.99                 | 0.94 | 4.21* | 0.99 | 0.143                          | 0.035    |
| 20 m      | 5.04                                                      | 0.61 | 4.82*  | 0.67 | 5.31                 | 0.63 | 4.85* | 0.61 | 0.005                          | 0.124    |
| PSP       | 16.11                                                     | 2.99 | 17.68* | 2.69 | 16.65                | 3.40 | 16.21 | 2.93 | 0.000                          | 0.225    |
| Enjoyment | 37.67                                                     | 5.61 | 39.73* | 4.50 | 35.24                | 5.10 | 35.85 | 5.08 | 0.040                          | 0.057    |

\* significant difference between t<sub>0</sub>-t<sub>1</sub>.

sprint ( $p < 0.05$ ). Moreover, post-intervention EG performed better in MBT and 20m than CG, while CG showed higher performance in SLJ.

However, there was a non-significant interaction effect between intervention group and time for lower (SLJ) and upper (MBT) limbs strength ( $p = 0.325$ ;  $p = 0.143$ ). The 20 m sprint analysis showed a significant intervention x time effect ( $p = 0.005$ ) with low effect size ( $\eta^2 = 0.125$ ).

Physical self-perception and enjoyment significantly increased in EG ( $p < .05$ ), but not in CG. Also, significant interaction effect was found for both variables ( $p = 0.000$ ), with an effect size of  $\eta^2 = 0.225$  for physical self-perception, and  $\eta^2 = 0.057$  for enjoyment.

## Discussion

The results of the study revealed differences in motor performance and self-report scores for physical fitness, physical self-perception, and enjoyment after an experimental intervention based on the variation of teaching styles. Although the results showed a significant improvement of the components of physical fitness in the EG and CG, the factors related to the practice of physical activity (self-perception and enjoyment) improved only in the EG.

This is important in the didactic field of physical education, from which a series of considerations may derive.

In fact, in EG children received more opportunities to choose and experiment with executive variants and motor responses, and this could lead not only to the development of physical fitness components (strength and speed), but also to the enhancement of motor coordination and to a greater perception of competence and enjoyment during practice than CG.

The development of self-perception and enjoyment are interdependent, and they arise from the results of successful motor tasks performed and the corresponding determined traces in the individual motor repertoire (Mosston & Answorth, 2008; Morgan, 2005; Ferrer-Caja & Weiss, 2000). The ways in which teaching styles vary and are interconnected are crucial for assessing the effects on motor learning and related psychological factors. They are not opposite but complementary: the continuum between the styles of reproduction and production is based on the relationship between the decision-making processes of the teacher and those of the student (Dudley, Okely, Pearson, & Cotton, 2011; Moy, Renshaw, Davids, & Brymer, 2019; Diloy-Peña et al., 2021). Production styles promote the development of motor coordination and related psychological factors,

essential components of motor skills and the study carried out highlighted. Previous studies in primary school have demonstrated the effects of variation in teaching styles (e.g., inclusion and practice) in a test/re-test intervention related to self-perception (Chatoupis & Emmanuel, 2003).

Morgan et al. (2005) highlighted that production styles (e.g. the guided discovery style) promote cognitive and affective responses compared to the use of reproduction styles (e.g., practice style).

Recently, Rivera-Pérez et al. (2020) has shown how the proposal of motor tasks with the teaching strategy of cooperative learning, both with reproduction (reciprocal and self-check styles) and production teaching styles (divergent discovery style) - promotes the development of emotional skills (emotional recognition, control and regulation of emotions, empathy) in children and adolescents. The development of lateral thinking, empathic and socio-relational skills of the child, as well as the construction of positive and constructive interactions within the group-class should be solicited more in primary school, for the acquisition of the values related to the motor experience in the different organizational modalities (Rivera-Pérez et al., 2020). In fact, the choice of teaching style has a strong impact on the way children learn (imitation; conditioning; tests and errors; intuition; understanding) and perform a motor task (Pill, 2023). In this sense, the variation of teaching styles in physical education and, more generally, in the field of motor activities, should be encouraged to solicit multiple and different cognitive abilities and ways of thinking of children (Moy, Renshaw & Davids, 2016).

Furthermore, there are differences between generalist and specialist teachers in the mastery of teaching styles and in the variation of content and this affects the children's learning processes and the quality of the motor experience. A recent study has highlighted different methodological approach between the teachers themselves according to the type of degree in physical education and sports sciences: sports science teachers' degree mainly used the command style, while those with physical education degree (or both PE and sports sciences degree) applied different and differentiated teaching styles and strategies (Fernández & Espada, 2021). In addition, the study of da Silva et al. (2020) highlights how production styles foster the learning of sports-oriented skills of team sports, being closely related to several factors, such as the ability to make decisions, select appropriate motor responses, and be active and participate in different game situations. Another study assessed the effects of two learning units, based on the command style and guided-discovery style, respectively, on the acquisition of gymnastic technical skills in primary school children. Although learning outcomes are similar in both groups, the guided-discovery style allows for greater learning retention in the medium to long term than that of command style (El Khouri et al., 2020)

## Conclusions

The present study highlights the effectiveness of the variation of teaching styles in PE to improve not only physical fitness, but also self-perception and enjoyment, that are correlates for guarantee better adherence to physical activity during lifetime. It has been showed that different teaching styles have different (but complementary) effects,

both physical and motivational, on children. However, the following limitations can be underlined: (a) sample's age (8-10 years) has not been considered as covariate, (b) the effect of BMI (normal weight, overweight, obese) has not been analyzed, (c) small sample, and (d) no evaluation of retention effect. Moreover, it might be important to analyze the mastery and knowledge of the teaching styles of specialist PE teachers before starting the experimental activities.

The study stressed the importance of adequate PE teachers training on the use of teaching styles in the didactic of motor activities. Physical education teacher training, in fact, should provide a significant importance in the university curriculum on the topics of the methodology of motor activities and the introduction to sport in the developmental age to highlight the effects on the formation of the person not only determined by the variety of content and organizational arrangements but, above all, determined by changes in the modalities of educational communication (methodology). Future research are needed to analyze the effects related to the use of teaching styles in different educational settings.

## Conflict of interest

The authors declare no conflict of interest.

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## ВИВЧЕННЯ ВПЛИВУ ВТРУЧАНЬ ІЗ ЗАСТОСУВАННЯМ РЕПРОДУКТИВНИХ І ПРОДУКТИВНИХ СТИЛІВ НАВЧАННЯ НА МОЛОДШИХ ШКОЛЯРІВ. ЯКІ МОЖЛИВІ НАСЛІДКИ ДЛЯ ВЧИТЕЛІВ ФІЗИЧНОГО ВИХОВАННЯ?

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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.** Останніми роками велику увагу приділяють дослідженню взаємозв'язку «вчитель-учень» у процесах викладання та навчання фізичного виховання. Попередні дослідження показали, що використання Спектру стилів навчання може підвищувати внутрішню мотивацію, задоволення, дотримання фізичної активності та рівень фізичної активності у дітей і підлітків.

**Мета дослідження.** Метою цього дослідження є здійснення оцінки, чи може втручання з фізичного виховання (ФВ) на основі різних варіантів стилів навчання, з огляду на продуктивні стилі, також мати позитивний вплив на фізичну підготовленість.

**Матеріали та методи.** Вибірка включала 4 класи початкової школи ( $n = 124$  дитини, середній вік = 8–10 років), залучених до участі в рамках проекту SBAM (Здоров'я, Гарне самопочуття, Навчання здорового харчування та Рух у школі) в Апулії, Південна Італія. Класи були випадковим чином розподілені на експериментальну групу (ЕГ) та контрольну групу (КГ). ЕГ проходила 5-місячне експериментальне втручання на основі варіювання стилів навчання, а КГ проходила звичайні заняття з фізкультури. Фізичну підготовленість оцінювали за допомогою тестів «Стрибок у довжину з місця» (СДМ), «Кидок медичного м'яча вагою 1 кг» (КММ) та «Спринт на 20 м» (20 м), а для оцінки фізичного самосприйняття (ФСС) і задоволення використовували два офіційно затверджених опитувальника. Для оцінки статистично значущої різниці та ефекту взаємодії до ( $t_0$ ) та після ( $t_1$ ) виконання протоколу втручання було проведено двофакторний (група втручання  $\times$  час) дисперсійний аналіз.

**Результати.** Аналіз даних показав статистично значуще покращення рівня фізичної підготовленості як в ЕГ, так і в КГ, а показники рівня ФСС і задоволення зросли лише в ЕГ. Крім того, статистично значущі ( $p < 0,05$ ) ефекти взаємодії були виявлені для змінних «Спринт на 20 м», «ФСС» та «Задоволення» з низьким показником розміру ефекту ( $\eta^2 \sim 0,20$ ).

**Висновки.** Результати цього дослідження підкреслюють ефективність втручання із ФВ на основі варіювання стилів навчання для покращення рівня фізичної підготовленості, самосприйняття та задоволення. Крім того, використання продуктивних стилів навчання статистично значуще впливає на показники самосприйняття та задоволення, які є важливими опосередковувальними чинниками для гарантування кращого дотримання фізичної активності.

**Ключові слова:** стилі навчання; модельна практика у фізичному вихованні; фізична підготовленість; поведінка вчителя; заохочення здорового способу життя.

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ORIGINAL SCIENTIFIC ARTICLE

## COMPARATIVE ANALYSIS OF THE EFFORTS OF HIGHLY QUALIFIED ELITE ARMWRESTLERS WITH DIFFERENT STRENGTH ABILITIES

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### Abstract

**Study purpose.** Determination of the peculiarities of the manifestation of strength in competitive exercises of highly qualified armwrestlers with different strength abilities.

**Materials and methods.** The study involved the 4 best armwrestlers in the world weighing from 80 to 100 kg ( $m = 87.50 \pm 2.47$  kg) in 2017-2020. Four power test exercises have been identified that ensure the performance of a competitive action in armwrestling: flexion of the fingers, stretch with a hammer, hook and bending the hand. Strength indicators in all test exercises were measured with an FL1K 0.5N, 1000N electric strain gauge dynamometer, Kern & Sohn GmbH (China), fixed on the armwrestling table using an author's block device.

**Results.** The results of the correlation analysis of the relationships between the studied indicators confirm the presence of a difference in the direction and strength of the relationships between the strength and time characteristics of the efforts of athletes with different strength and speed-strength abilities. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength ( $r = 0.926-0.999$ ), of which 7 modules are with time and 4 modules are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections ( $r = 0.916-0.948$ ) and 8 modules with strong connections ( $r = 0.739-0.886$ ), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. But the other correlation indicators have very weak ( $r < 0.29$ ) and weak ( $r = 0.3-0.5$ ) levels of relationships.

**Conclusions.** Analysis of the time and force characteristics of the manifestation of force in the process of achieving boundary resistance allows us to clearly establish the genetically determined speed and strength abilities of the explosive, fast and slow force of armwrestlers.

**Keywords:** armsport, armwrestling, armwrestlers, explosive power, strength indicators.

### Introduction

The preparation of highly qualified athletes is the main object of research in modern science and sports, which solves the problem of developing the foundations for the rational organization of the training process. The most important element of such an organization can be a system of comprehensive monitoring of athletes' preparedness levels, taking into account all formative factors. In this regard, there is a need to accurately determine the indicators

of the level of sportsmanship of an arm wrestler, especially at the stage of preparation for the main start, that is, at the stage of pre-competition specialized training. Since the technical and tactical training of highly qualified athletes is at approximately the same level, special attention must be paid to control over strength and speed-strength indicators (Mazurenko, 2019).

Studying the experience of preparing and performing in competitions of world armwrestling leaders provides unique information that concentrates the positive experience of the athlete (Podrihalo et al., 2021; Bezkorovainyi et al., 2022). However, to date, the methodological aspects of constructing individual training processes of the world's leading armwrestlers have not yet become the object of close

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attention of researchers. Such works are rare (Bezkorovainyi et al., 2019; 2023), although their significance from both theoretical and practical points of view is beyond doubt.

An analysis of the practice of competitive activity of armwrestlers shows that the duration of a fight in this sport can range from a few tenths of seconds to tens of minutes in some cases (Ahamed et al., 2013). At the beginning of the fight, both opponents show explosive power. Subsequently, the athlete who seized the initiative shows fast and slow force (Akpina et al., 2013). The effectiveness of the manifestation of these traits depends on the level of strength endurance (Burdukiewicz et al., 2018).

During the fight, the arm muscles in most cases perform work in the aucontontonic (combined) mode, when all three modes of muscle work are alternated or summed up – myometric (concentric), plyometric (eccentric) and isometric. This combined mode manifests itself when fighting from a few tenths of a second to tens of minutes. With such duration of the fight, strength endurance will be of great importance, and vice versa, when victory is quickly achieved (in a few seconds), the muscles perform work in a biometric mode, overcoming the efforts of the opponent due to high of explosive force (Ogawa et al., 2022; Hirai, 2021).

Based on the results of our previous studies (Bezkorovainyi et al., 2019; 2022; 2023), it was established that the explosive force of highly skilled armwrestlers is formed by the starting and accelerating force. The starting force manifests itself in the first 200 ms, which is accompanied by a rapid increase in force that does not reach the limit values, as well as a maximum increase in the speed-force index, which obviously makes it possible to develop maximum acceleration during of this time. Subsequently, fast force appears, characterized by an increase in the force to overcome resistance, which has not yet reached the limit value, as well as a decrease in the speed-force index and, accordingly, a decrease in acceleration. As the fight continues, overcoming the opponent's resistance reaches a limiting value, and the acceleration is relatively stabilized. The strength displayed at this stage of the fight is characterized by slow strength. The duration and magnitude of the manifestation of fast and especially slow force depend on the level of strength endurance of the arm wrestler (Kamayev et al., 2020, 2021; Zixiang Tong, 2021).

In connection with such features of armwrestling, in order to determine an effective methodology of the training process that corresponds to the volume and intensity of the loads and their direction, it is especially important to establish the natural strength abilities of the athlete and their significance in achieving successful competitive activity.

In connection with the above, the purpose of this study was to determine the characteristics of the manifestation of strength in competitive exercises by highly qualified armwrestlers with different strength abilities.

## Material and Methods

### Participants

The study involved 4 leading arm wrestlers in the world weighing from 80 to 100 kg (average weight  $87.50 \pm 2.47$  kg). Athlete 1 (age 38) – multiple world champion weighing 90 kg (Ukraine), athlete 2 (age 32) – multiple medalist of

international competitions weighing 85 kg (USA), athlete 3 (age 28) – multiple world champion weighing 82 kg (Ukraine), athlete 4 (age 33) – multiple world champion weighing 93 kg (Ukraine). All athletes consented to the study.

### Research Design

Strength and speed capabilities in test exercises were determined by an electrical tenzodynamometer of the FL1K 0.5N, 1000N series, Kern & Sohn GmbH (China) with an accuracy class of up to 50 g, fixed on a specialized table for armwrestling using an author's specially made block device – “ARM2 device”. The strength and speed capabilities of armwrestlers were determined based on the results of four test exercises covering the main muscle groups that ensure the performance of a competitive action, namely: flexion of fingers, stretch with a hammer, hook and bending the hand (Kamayev et al, 2021). All exercises were performed with both left and right hands.

Measurements of strength and speed-strength indicators of each of the athletes were carried out three times within three years (2017-2020), after the end of the main competition of the year (armwrestling championship or world cup). They made three attempts in each movement on the left and right hands, after measurements the best results were selected.

When measuring the strength of the muscles of the hands and speed-strength indicators, the subject stood facing the table, grabbed the special handles of the device with a brush and squeezed them with maximum force, trying to show maximum force as soon as possible. Flexion of fingers was performed with a special eccentric 3D handle, which the athlete grabbed and pressed with his fingers into the platform, the pressure vector was directed to the chest. Stretch with a hammer was performed with a fabric loop, the pressing vector was directed to the forehead. The hook was performed with a rotating handle with a diameter of 30 mm, which the athlete grabbed and tried to pull up to the chest, simulating a hook fight. The block was located on the left or right sides of the table, respectively. Bending the hand was performed with a rotating handle with a diameter of 45 mm, which the athlete grabbed and tried to bend the hand towards the chest. The distance and angle between the handles of the device was easily changed and selected for each exercise.

The special computer program AFH-FASTFD made it possible to process the measurement data in real time (on-line) and the previously collected data from the memory of the electrical tenzodynamometer (off-line). AFH-FASTFD is compatible with the operating systems Windows.

### Statistical Analysis

Statistical analysis of the obtained data was carried out using the licensed program STATISTICA 10. The following parameters were determined and calculated: maximum ( $F$ ) and relative ( $F_1 = \Sigma F/m$ ) strength, kg; total strength index in four strength exercises ( $\Sigma F = F_1 + F_2 + F_3 + F_4$ ), kg; time to reach maximum strength ( $\Sigma t = t_1 + t_2 + t_3 + t_4$ ), s; speed-strength index ( $J = \Sigma F/\Sigma t$ ), kg/ms; average strength, index of four exercises ( $\bar{F} = \Sigma F/4$ ), kg; total strength gradient of four

exercises ( $\Sigma t_{0.5F}$ ), ms; speed-strength index in the first 500 ms ( $J_{500} = \Sigma F_{500} / \Sigma t_{500}$ ), kg/ms; time to reach 1 kg force ( $t_1 = \Sigma t_{0.5F} / (0.5 \times F)$ ), ms/kg; Wilcoxon-White test; the coefficient of variation; Spearman correlation analysis.

## Results

According to our latest research (Bezkorovainyi et al., 2019, 2022, 2023), it has been established that among highly qualified arm wrestlers, multiple winners and prize-winners of world and European championships, national championships (USA, Poland, Ukraine), each athlete has purely individual natural abilities and a correspondingly

high level of special preparedness. The main thing where they differ is in the indicators of maximum strength and speed-strength capabilities.

From a number of strong armwrestlers weighing from 80 to 100 kg, four of the most titled athletes were singled out, who are especially different from other athletes. These are two armwrestlers with high levels of explosive power and two athletes with pronounced maximum strength and strength endurance.

Analysis of the overall results of achieving maximum performance in four test exercises (flexion of fingers, stretch with a hammer, hook and bending the hand) indicates that armwrestlers of the strength group (athletes 1 and 2) differ

**Table 1.** Features of the strength and time characteristics of the manifestation of strength by armwrestlers with different strength abilities

| Indicator                  | Athlete | Left arm | Right arm | Hand sum | Group sum | X±m            | t-test                                                         | V, %  |
|----------------------------|---------|----------|-----------|----------|-----------|----------------|----------------------------------------------------------------|-------|
| ΣF, kg                     | 1       | 233.80   | 260.50    | 494.30   | 886.50    | 221.62±15.89   | t=0.74; P>0.05; (t <sub>fact</sub> 16 > t <sub>table</sub> 11) | 14.34 |
|                            | 2       | 190.00   | 202.20    | 392.20   |           |                |                                                                |       |
|                            | 3       | 326.50   | 173.50    | 500.00   | 990.20    | 249.55±31.48   |                                                                | 25.43 |
|                            | 4       | 236.10   | 254.10    | 490.20   |           |                |                                                                |       |
| F̄, kg                     | 1       | 58.45    | 65.12     | 123.57   | 221.92    | 55.48±3.92     | t=0.73; P>0.05; (t <sub>fact</sub> 16 > t <sub>table</sub> 11) | 14.15 |
|                            | 2       | 47.80    | 50.55     | 98.35    |           |                |                                                                |       |
|                            | 3       | 81.62    | 43.87     | 125.49   | 248.03    | 61.88±7.87     |                                                                | 25.44 |
|                            | 4       | 59.02    | 63.52     | 122.54   |           |                |                                                                |       |
| Σt, s                      | 1       | 5.3      | 5.5       | 10.8     | 19.9      | 4.97±0.32      | t=2.79; P<0.05; (t <sub>fact</sub> 10 < t <sub>table</sub> 11) | 14.08 |
|                            | 2       | 3.9      | 5.2       | 9.1      |           |                |                                                                |       |
|                            | 3       | 6.6      | 5.9       | 12.5     | 28.5      | 7.12±0.70      |                                                                | 20.00 |
|                            | 4       | 6.8      | 9.2       | 16       |           |                |                                                                |       |
| J, kg/s                    | 1       | 44.11    | 47.36     | 91.47    | 178.72    | 44.77±3.12     | t=1.62; P>0.05; (t <sub>fact</sub> 14 > t <sub>table</sub> 11) | 13.96 |
|                            | 2       | 48.37    | 38.88     | 87.25    |           |                |                                                                |       |
|                            | 3       | 49.47    | 35.41     | 84.88    | 147.22    | 35.30±4.95     |                                                                | 28.07 |
|                            | 4       | 34.72    | 27.62     | 62.34    |           |                |                                                                |       |
| F1, kg/kg                  | 1       | 2.59     | 2.89      | 5.48     | 10.1      | 2.52±0.14      | t=0.75; P>0.05; (t <sub>fact</sub> 17 > t <sub>table</sub> 11) | 16.50 |
|                            | 2       | 2.24     | 2.38      | 4.62     |           |                |                                                                |       |
|                            | 3       | 3.98     | 2.12      | 6.1      | 11.37     | 2.84±0.40      |                                                                | 28.16 |
|                            | 4       | 2.54     | 2.73      | 5.27     |           |                |                                                                |       |
| Σt0,5F, ms                 | 1       | 910      | 1410      | 2320     | 3895      | 948.74±161.40  | t=3.69; P<0.05; (t <sub>fact</sub> 10 < t <sub>table</sub> 11) | 34.02 |
|                            | 2       | 670      | 905       | 1575     |           |                |                                                                |       |
|                            | 3       | 2046     | 1935      | 3981     | 8231      | 2058.75±258.25 |                                                                | 25.07 |
|                            | 4       | 1500     | 2750      | 4250     |           |                |                                                                |       |
| ΣF500, kg                  | 1       | 195.9    | 204.9     | 400.8    | 712.8     | 178.2±12.94    | t=1.84; P>0.05; (t <sub>fact</sub> 13 > t <sub>table</sub> 11) | 14.50 |
|                            | 2       | 156      | 156       | 312      |           |                |                                                                |       |
|                            | 3       | 202.8    | 106.7     | 309.5    | 496.3     | 124.07±26.43   |                                                                | 42.60 |
|                            | 4       | 93       | 93.8      | 186.8    |           |                |                                                                |       |
| J500, g/ms                 | 1       | 97.95    | 102.45    | 200.4    | 356.4     | 89.1±6.47      | t=1.83; P>0.05; (t <sub>fact</sub> 13 > t <sub>table</sub> 11) | 14.50 |
|                            | 2       | 78       | 78        | 156      |           |                |                                                                |       |
|                            | 3       | 101.4    | 53.35     | 154.75   | 248.15    | 62.04±13.21    |                                                                | 42.60 |
|                            | 4       | 46.5     | 46.9      | 93.4     |           |                |                                                                |       |
| t1, ms/kg                  | 1       | 7.73     | 10.82     | 18.55    | 33.56     | 8.39±0.83      | t=3.14; P<0.05; (t <sub>fact</sub> 10 < t <sub>table</sub> 11) | 19.8  |
|                            | 2       | 7.05     | 7.96      | 15.01    |           |                |                                                                |       |
|                            | 3       | 12.53    | 22.31     | 34.84    | 69.19     | 17.30±2.70     |                                                                | 31.30 |
|                            | 4       | 12.71    | 21.64     | 34.35    |           |                |                                                                |       |
| J <sub>finish</sub> , kg/s | 1       | 10.82    | 12.36     | 23.18    | 55.51     | 13.88±1.22     | t=5.45; P<0.05; (t <sub>fact</sub> 10 < t <sub>table</sub> 11) | 17.65 |
|                            | 2       | 17.89    | 14.44     | 32.33    |           |                |                                                                |       |
|                            | 3       | 26.89    | 23.03     | 49.92    | 101.99    | 25.50±1.75     |                                                                | 3.92  |
|                            | 4       | 29.81    | 22.26     | 52.07    |           |                |                                                                |       |

from fast athletes (athletes 3 and 4) by 11.7 % strength data (990.2 kg versus 886.5 kg). This difference remains in the average strength indicators ( $247.55 \pm 31.48$  kg versus  $221.62 \pm 15.89$  kg), but this difference turned out to be unreliable (Table 1). This is explained by the high coefficient of variation of 25.43 % and 14.34 %, respectively.

A similar difference between the strength capabilities of these athletes according to the average test indicators is completely preserved.

In terms of the time to reach maximum strength, the first two athletes showed a significantly better result compared to the other two athletes –  $4.97 \pm 0.32$  s versus  $7.12 \pm 0.70$  s. The difference between these indicators of 43.2 % provided significant differences between them –  $t = 2.79$ ;  $P < 0.05$  (Table 1).

In connection with such temporary characteristics of the efforts of armwrestlers, athletes 1 and 2 demonstrated 26.8 % higher speed-strength index values, respectively,  $44.77 \pm 3.12$  kg/s versus  $35.30 \pm 4.95$  kg/s than athletes 3 and 4. Moreover, the difference between such data is unreliable –  $t = 1.62$ ;  $P > 0.05$ . The high result of achieving maximum strength with the left arm (326.5 kg) and the relatively small body weight (82 kg) of athlete 3 allowed the second pair to demonstrate higher relative strength – 2.84 kg versus 2.54 kg the first two athletes. Considering the increased coefficient of variation (28.16 % and 16.50 %), the difference between these data also turned out to be unreliable –  $t = 0.75$ ;  $P > 0.05$ .

Determining the force gradient (the time to reach half the maximum force) made it possible to establish high speed-strength capabilities of the first pair. Thus, athletes 1 and 2 demonstrated better results by 2.17 times compared to athletes 3 and 4 –  $948.75 \pm 161.40$  ms versus  $2057.75 \pm 259.25$  ms. Thanks to this difference, despite the rather high coefficients of variation (34.02 % and 25.17 %), these data are significantly different ( $t = 3.69$ ;  $P < 0.05$ ;  $t_{\text{fact}} 10 < t_{\text{table}} 11$ ).

Analysis of strength achievements for 500 ms indicates the highest strength capabilities of athletes 1 and 2. Thus, during this time they reached a level of  $178.20 \pm 12.94$  kg, and arm wrestlers 3 and 4 showed  $124.07 \pm 26.13$  kg. But the difference between these results is insignificant ( $t = 1.84$ ;  $P > 0.05$ ), since in this case the variability of the statistical aggregates is also large (14.5 % and 42.6 %). Due to the same test execution time, the speed-strength indicator in this test completely repeats the strength capabilities data for this time.

Calculation of the time athletes reach a force of 1 kg also confirms the high speed-strength abilities of armwrestlers 1 and 2. The data obtained allows us to establish that these athletes demonstrated better results by 2.06 times than arm wrestlers 3 and 4 –  $8.39 \pm 0.83$  ms versus  $17.30 \pm 2.70$  ms. This is supported by the reliability of the difference in indicators –  $t = 3.14$ ;  $P < 0.05$ .

According to the results of determining the speed-strength indicator at the last second of the test, armwrestlers 3 and 4 showed a significantly higher result, which was 1.84 times (83.7 %) higher than the achievement of athletes 1 and 2 ( $25.50 \pm 1.75$  kg/s versus  $13.88 \pm 1.22$  kg/s). Such data differ significantly from each other –  $t = 5.45$ ;  $P < 0.01$ ;  $t_{\text{fact}} 10 < t_{\text{table}} 11$ ).

In this study, the significance of differences between the achievements of armwrestlers was tested using the nonparametric Wilcoxon-White test for independent samples. The Student's t-test data are fully confirmed by the Wilcoxon-White test.

Analyzing the results of the study, we can summarize that all strength indicators, which were determined without taking into account the time characteristics of efforts, were better in athletes 3 and 4. It is especially noticeable that armwrestler 3 demonstrated very high results in strength tests with his left hand. In this regard, obviously, he won all significant victories in competitions with his left hand. His right arm is the weakest in all strength tests.

Armrestler 2 demonstrated small strength data, but was the fastest in all indicators of time characteristics of efforts.

Armrestler 1 has equally high performance in both strength and time characteristics of efforts. His results are the most harmonious, therefore, of all four athletes, he is the most titled.

Athlete 4 also has relatively high strength data, but the time characteristics of performing efforts are noticeably weaker, and his sporting achievements are less effective.

The results of the correlation analysis of the relationships between the studied indicators confirm the presence of a difference in the direction and strength of the relationships between the strength and time characteristics of the efforts of athletes with different strength and speed-strength abilities. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength ( $r = 0.926-0.999$ ), of which 7 modules are with time and 4 are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections ( $r = 0.916-0.948$ ) and 8 with strong connections ( $r = 0.739-0.886$ ), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. But other correlation indicators have very weak ( $r < 0.29$ ) and weak ( $r = 0.3-0.5$ ) levels of relationships.

Considering that the main differences in the reaction of arm wrestlers to test exercises are related to the temporal characteristics of efforts and the peculiarities of conducting a fight in competitions, it was especially important to analyze the dynamics of the studied characteristics at the beginning of strength exercises.

Thus, at the beginning of a strength exercise within 100 ms, not all athletes have time to engage in the exercise. Athletes 2 and 3 showed zero reaction with their right hands. At the same time, athlete 2 with his left hand reached a level of 106.2 kg (Table 2), and in a total of 100 ms, armwrestlers 1 and 2, according to average statistical data, showed 2.45 times greater strength compared to the results of athletes 3 and 4 (48.97 kg vs. 20.00 kg). Despite this discrepancy, the difference between these results is unreliable, since the coefficients of variation are very large (68.12 % and 64.00 %).

Accordingly, with such dynamics of growth in strength indicators, the indicators of the speed-strength index change (Table 3).

Between 100 ms and 200 ms of the testing process, strength indicators increase significantly, namely for athletes 1 and 2 by 2.26 times (from 48.97 kg to 125.5 kg), for armwrestlers 3 and 4 – by 3.3 times (from 20.00 to 66.15 kg). The difference between the achievements of both pairs of athletes was 89.7 %. Such a difference in this case indicates significant differences ( $t = 3.93$ ;  $P < 0.05$ ) between strength indicators at this stage of the study (Table 2). The rate of increase in the speed-strength index between 100 ms and 200 ms is much lower compared to strength indicators. Thus,

**Table 2.** Dynamics of power characteristics of arm efforts in competitive exercises when testing armwrestlers (kg)

| Indicator                | Athlete | Left arm | Right arm | Hand sum | Group sum | X±m          | t-test         | V, %  |
|--------------------------|---------|----------|-----------|----------|-----------|--------------|----------------|-------|
| F <sub>100</sub> , kg    | 1       | 53.7     | 36.0      | 89.7     | 195.9     | 48.94±16.6   | t=1.63; P>0.05 | 68.12 |
|                          | 2       | 106.2    | 0         | 106.2    |           |              |                |       |
|                          | 3       | 19.8     | 0         | 19.8     | 80        | 20.00±6.4    |                | 64.00 |
|                          | 4       | 42.1     | 18.1      | 60.2     |           |              |                |       |
| F <sub>200</sub> , kg    | 1       | 125.4    | 119.7     | 245.1    | 502.2     | 125.50±4.19  | t=3.92; P<0.05 | 6.61  |
|                          | 2       | 119.6    | 137.5     | 257.1    |           |              |                |       |
|                          | 3       | 109.7    | 54.8      | 164.5    | 264.6     | 66.15±14.55  |                | 44    |
|                          | 4       | 51.7     | 48.4      | 100.1    |           |              |                |       |
| F <sub>300</sub> , kg    | 1       | 161.9    | 174.3     | 336.2    | 627.1     | 156.77±7.43  | t=3.86; P<0.05 | 9.59  |
|                          | 2       | 139.5    | 151.4     | 290.9    |           |              |                |       |
|                          | 3       | 153.6    | 81.2      | 234.8    | 381.3     | 95.32±19.64  |                | 41.21 |
|                          | 4       | 78.7     | 67.8      | 146.5    |           |              |                |       |
| F <sub>500</sub> , kg    | 1       | 195.9    | 204.9     | 400.8    | 712.8     | 178.20±12.94 | t=1.96; P>0.05 | 14.54 |
|                          | 2       | 156      | 156       | 312      |           |              |                |       |
|                          | 3       | 202.8    | 106.7     | 309.5    | 496.3     | 124.10±24.42 |                | 42.68 |
|                          | 4       | 93       | 93.8      | 186.8    |           |              |                |       |
| F, kg                    | 1       | 233.8    | 260.5     | 494.3    | 886.8     | 221.62±25.89 | t=0.74; P>0.05 | 14.34 |
|                          | 2       | 190      | 202.5     | 392.5    |           |              |                |       |
|                          | 3       | 326.5    | 173.5     | 500      | 990.2     | 247.55±31.48 |                | 25.43 |
|                          | 4       | 236.1    | 254.1     | 490.2    |           |              |                |       |
| Ff <sub>inish</sub> , kg | 1       | 37.9     | 55.6      | 93.5     | 174.0     | 43.50±4.80   | t=3.53; P<0.05 | 22.10 |
|                          | 2       | 34.0     | 46.5      | 80.5     |           |              |                |       |
|                          | 3       | 123.7    | 66.8      | 190.5    | 493.9     | 123.50±22.2  |                | 35.90 |
|                          | 4       | 143.1    | 160.3     | 303.4    |           |              |                |       |

in athletes 1 and 2 the increase was 28.2 % (from 0.489 kg/ms to 0.627 kg/ms), and in athletes 3 and 4 – 65.0 % (from 0.200 kg/ms to 0.330 kg/ms). The difference between the achievements of armwrestlers during this time, as well as in the strength data, is significant ( $t = 4.18$ ;  $P < 0.05$ ) (Table 3).

In the subsequent period of time from 200 ms to 300 ms, strength indicators gradually increase. For athletes 1 and 2 the increase was 24.9 % (from 125.50 kg to 156.77 kg), and for athletes 3 and 4 this figure increased from 66.25 kg to 95.32 kg (43.88 %). The difference between these indicators of both pairs of arm wrestlers (156.77 kg and 95.32 kg) was significant ( $t = 3.86$ ;  $P < 0.05$ ) (Table 2).

During this time period, the speed-strength index begins to decline. Thus, in athletes 1 and 2 it decreased from 0.627 kg/ms to 0.523 kg/ms (by 19.9 %), and in athletes 3 and 4 the rate of decrease was only 4.1 % (from 0.330 kg/ms to 0.317 kg/ms). Despite such rates of decline, the data of the first pair are significantly better than the results of the second pair –  $t = 2.98$ ;  $P < 0.05$  (Table 3).

In the next 200 ms (from 300 ms to 500 ms), naturally, the influence of force continues to grow in both pairs of athletes. The growth rate of strength indicators in athletes 3 and 4 is still significantly higher. Thus, for these armwrestlers the magnitude of the force impact increased from 95.23 kg to 124.1 kg (by 32.2 %), and for athletes 1 and 2 – by 13.4 % (from 156.77 kg to 178.20 kg). The difference between these results turned out to be unreliable –  $t = 1.96$ ;  $P > 0.05$ . And the speed-strength index decreases more rapidly in athletes 1 and 2 – by 76.9 % (from 0.523 kg/ms to 0.356 kg/ms), in the second pair of armwrestlers the rate of decrease was 27.3 % (from 0.356 kg/ms to 0.249 kg/ms). The difference between such data also turned out to be insignificant ( $t = 1.84$ ;  $P > 0.05$ ) (Table 2, 3).

Subsequently, a gradual increase in strength continues until maximum strength is achieved in both pairs of athletes. The time to reach maximum strength, as noted earlier, varies significantly. So, for the first pair this time was 4.97 s, and for the second – 7.12 s. Armwrestlers 1 and 2 reached 221.62 kg during this time, and athletes 3 and 4 reached 247.55 kg over a longer period of time. The difference between these indicators is insignificant –  $t = 0.74$ ;  $P > 0.05$ .

When maximum strength was achieved, the speed-strength index indicators were: for the first pair – 0.045 kg/ms, and for the second – 0.035 kg/ms. The difference between these data was 25.57 %, but due to large coefficients of variation (23.91 % and 27.70 %), the discrepancy turned out to be unreliable ( $t = 1.47$ ;  $P > 0.05$ ) (Table 3).

During the time remaining before reaching the maximum strength of 2.97 s ( $4.97 - 0.5 \cdot 4$  s), the strength indicator of the first pair of athletes 5.12 s ( $7.12 - 0.5 \cdot 4$  s) increases by 24.4 % (from 178.20 kg to 221.62 kg), and for the second – by 99.5 % (from 124.10 kg to 247.55 kg).

Thus, the dynamics of power characteristics of effort observed during the specified period allows us to assert that athletes 3 and 4 have high power endurance. Armwrestlers 1 and 2 have significantly higher power characteristics in the first 200 ms and 300 ms of effort, which provides them with quick victories. According to the results of our research, such dynamics of power characteristics are achieved due to a high speed-strength indicator, starting from 100 ms of the beginning of the effort.

Analyzing the data obtained on the discrepancy between strength indicators, time characteristics and the level of strength endurance depending on the genetically determined abilities of highly qualified arm wrestlers, it is necessary to

**Table 3.** Dynamics of speed-strength index characteristics during testing of armwrestlers

| Indicator                | Athlete | Left arm | Right arm | Hand sum | Group sum | X±m         | t-test         | V. %  |
|--------------------------|---------|----------|-----------|----------|-----------|-------------|----------------|-------|
| J <sub>100</sub> , kg/ms | 1       | 0.537    | 0.36      | 0.897    | 1.959     | 0.489±0.170 | t=1.59; P>0.05 | 77.50 |
|                          | 2       | 1.062    | 0         | 1.062    |           |             |                |       |
|                          | 3       | 0.198    | 0         | 0.198    | 0.8       | 0.200±0.064 |                | 64.00 |
|                          | 4       | 0.421    | 0.181     | 0.602    |           |             |                |       |
| J <sub>200</sub> , kg/ms | 1       | 0.627    | 0.598     | 1.225    | 2.51      | 0.627±0.021 | t=4.18; P<0.05 | 6.63  |
|                          | 2       | 0.598    | 0.687     | 1.285    |           |             |                |       |
|                          | 3       | 0.548    | 0.274     | 0.822    | 1.322     | 0.330±0.072 |                | 43.90 |
|                          | 4       | 0.258    | 0.242     | 0.5      |           |             |                |       |
| J <sub>300</sub> , kg/ms | 1       | 0.54     | 0.581     | 1.121    | 2.091     | 0.523±0.024 | t=2.98; P<0.05 | 9.35  |
|                          | 2       | 0.465    | 0.505     | 0.97     |           |             |                |       |
|                          | 3       | 0.512    | 0.27      | 0.782    | 1.27      | 0.317±0.065 |                | 41.00 |
|                          | 4       | 0.262    | 0.226     | 0.488    |           |             |                |       |
| J <sub>500</sub> , kg/ms | 1       | 0.392    | 0.409     | 0.801    | 1.425     | 0.356±0.025 | t=1.84; P>0.05 | 14.30 |
|                          | 2       | 0.312    | 0.312     | 0.624    |           |             |                |       |
|                          | 3       | 0.41     | 0.213     | 0.623    | 0.997     | 0.243±0.053 |                | 43.00 |
|                          | 4       | 0.186    | 0.188     | 0.374    |           |             |                |       |
| J, kg/ms                 | 1       | 0.044    | 0.047     | 0.091    | 0.179     | 0.045±0.021 | t=1.47; P>0.05 | 23.91 |
|                          | 2       | 0.049    | 0.039     | 0.088    |           |             |                |       |
|                          | 3       | 0.049    | 0.029     | 0.078    | 0.141     | 0.035±0.048 |                | 27.70 |
|                          | 4       | 0.035    | 0.028     | 0.063    |           |             |                |       |

compare the features of the formation of explosive, fast and slow strength in these athletes. Since our previous studies (Bezkorovainyi & Kamayev, 2023) noted that explosive force is formed by starting and accelerating forces, it was found that explosive force in arm wrestlers manifests itself in the first 300 ms, and starting force manifests itself within 200 ms of effort. Within 100 ms, cases of zero reaction at the beginning of the effort are observed in both pairs of athletes under study (Table 2). But during this time, athletes 1 and 2 had a strength indicator and speed-strength index that was 2.45 times higher than that of arm wrestlers 3 and 4 (48.97 kg versus 20.00 kg) (Fig. 1).

Over 200 ms, the growth rates of both indicators in the second pair of athletes are higher, so the strength is 3.33 times higher, and the speed-strength index is 1.65 times higher (Fig. 1). But despite this difference in increase, the strength indicator and speed-strength index of athletes 1 and 2 are significantly higher than those of armwrestlers 3 and 4 (125.5 kg versus 66.15 kg) –  $t = 4.18$ ;  $P < 0.05$  (Table 2, 3). The high starting strength of the first pair is supported by a significantly higher speed-strength index.

Between 200 ms and 300 ms, under the conditions of the onset of muscle contraction, the process of increasing acceleration and increasing working force occurs, which

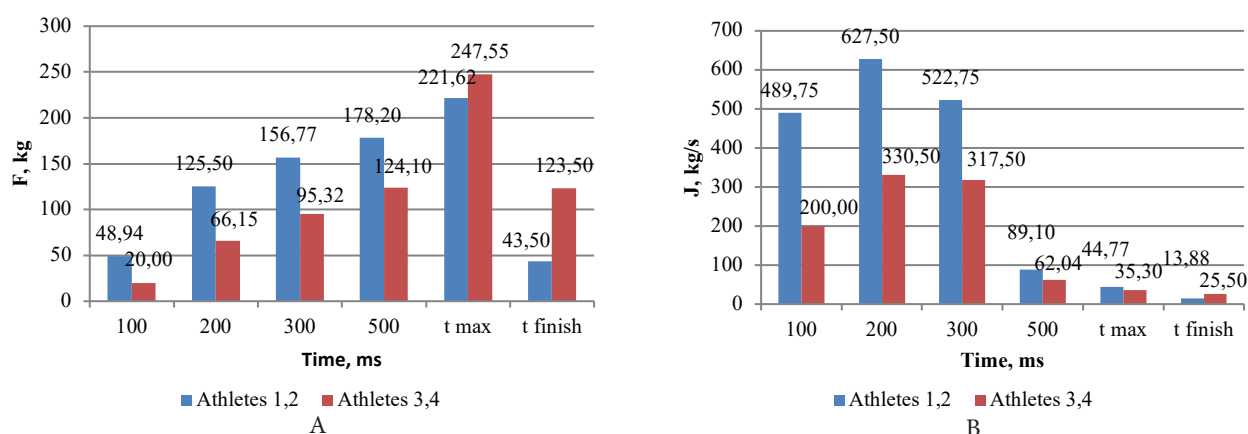


**Fig. 1.** Dynamics of strength indicators (A) and speed-strength index (B) of armwrestlers in different time periods of testing

corresponds to the accelerating force. During this time period, the formation of explosive force is completed and the beginning of a decrease in the speed-strength index in both pairs is noted, respectively, by 16.7 % in the first and by 3.9 % in the second (Fig. 1). During this period of time, athletes 1 and 2 have significantly higher levels of strength and speed-strength index compared to the data of arm wrestlers 3 and 4 ( $t = 3.86$ ;  $P < 0.05$  – in strength;  $t = 2.89$ ;  $P < 0.05$  – speed-strength index).

In the next period of time (from 300 ms to 500 ms), the speed-strength index decreases with great intensity: in athletes 1 and 2 – by 5.86 times, and in athletes 3 and 4 – by 5.12 times. From this we can state that the acceleration becomes significantly less than the maximum, and the strength indicator continues to increase in the first pair by 13.67 %, in the second – by 30.00 %, but the strength has not yet reached the limit values. The difference between strength indicators and speed-strength indices is unreliable, respectively –  $t = 1.96$ ;  $P > 0.05$  and  $t = 1.84$ ;  $P > 0.05$ . This creates fast force.

During the time that remains until the limit strength indicators are reached (for the first pair of athletes – 2.97 s, for the second – 5.12 s), the strength of arm wrestlers 1 and 2 increases by 24.4 % (from 178.20 kg to 221.62 kg), and athletes 3 and 4 – by 99.5 % (from 124.10 kg to 247.55 kg). The difference between these indicators is not significant ( $t = 0.74$ ;  $P > 0.05$ ). During this period of time, the speed-strength index continues to decrease, but with less intensity. So, for the first couple the decrease was 49.75 %, and for the second – 43.1 %.

When the maximum strength values were reached in athletes 1 and 2, the speed-strength indicator decreased to 44.77 kg/s, and in athletes 3 and 4 – to the level of 35.30 kg/s. This difference between the strength and speed-strength characteristics of the effort is explained by the large difference (52.6 %) in the time to achieve maximum strength between athletes. The manifestation of slow strength corresponds to a significant decrease in the speed-strength indicator and a slowdown in its pace when the maximum strength values are reached. The amount and time of application of this force until maximum force is achieved depends on the level of strength endurance. Proof of this statement in this study is the calculation of the strength index (123.50 kg vs. 43.5 kg;  $t = 3.52$ ;  $P < 0.05$ ) and speed-strength index (25.50 kg/s vs. 13.88 kg/s;  $t = 5.45$ ;  $P < 0.01$ ) at the last second in the second pair was significantly higher compared to the indicators of the first pair.

A comparative analysis of the strength and speed-strength indicators of the left and right hands allows us to state that the difference between them in both pairs is unreliable, however, in the second pair of athletes the discrepancy between the left and right hands fluctuates within 33.5 % to 88.2 %, and in the first – from 4.6 % to 47.6 %.

## Discussion

In arm wrestling there are many examples when arm wrestlers weighing from 80 to 100 kg take part in competitions for absolute superiority at national championships, as well as European and world championships, and international competitions (Min Kyung-hyun et al., 2018). I would also like to note that these athletes often defeated super-

heavyweights who weighed 20-50 kg or more. This is what attracts special attention from spectators, fans, athletes, coaches and, of course, researchers (Diffrient, 2019; Silva et al., 2009), when lighter athletes, inferior to anthropometric data, win due to strength and speed-strength indicators. All of these individuals are interested in determining the strongest athlete of the tournament, country, continent and even the world. Therefore, it is this weight category that is given special attention, and it became the object of our research. Taking into account the peculiarities of the external characteristics of the physique of such athletes, their techniques and tactics of conducting a fight, it is especially important to determine the most effective and influential characteristics of the manifestation of force that ensure the success in armwrestling.

The study was carried out over three years, since, as noted above, athletes weighing from 80 to 100 kg took part in competitions for absolute championship and received prizes. The four athletes selected for the study had the best indicators of both strength and speed-strength indicators, which was also confirmed by the results of participation in competitions.

However, despite the higher qualifications of the athletes who participated in the study, it must be recognized that the number of arm wrestlers who won world-class competitions is limited by the small size of the specialized sample. To date, a study has been conducted of winners of world and European level competitions weighing 60-80 kg (Bezkorovainyi et al., 2019; 2021; Mazurenko, 2019) and athletes weighing more than 100 kg (Bezkorovainyi, 2023). It should also be noted that the small sample is due to the small number of highly qualified athletes of this level of preparedness who agreed to conduct research with them.

But, in our opinion, the value of the results obtained lies in the fact that they coincide with the data obtained in the study of highly qualified athletes in the weight categories of 60-80 kg and more than 100 kg (Bezkorovainyi, 2023).

To conduct the study, the author's device was used to measure both strength and time indicators of the development of dynamic strength. This device differed from others (Vlasko & Dzhy, 2023) used in research in that it was highly mobile, easy to transport and assemble, and also accurately measured forces up to 50 g and time up to 100-110 ms. Other researchers have determined absolute strength as well as static endurance, which is measured using conventional dynamometers and stopwatches (Harčarik et al., 2020). The author's device allows you to automate measurements, as well as create a database about the strength and speed-strength capabilities of armwrestlers.

According to preliminary studies (Podrigalo et al., 2021; Rovnaya et al., 2019), it was found that arm wrestlers, based on genetic attachment, can be divided into those who have a tendency to quickly perform competitive exercises, and those who have the ability to perform strength endurance. Based on this, the four athletes under study were divided into two pairs with different strength and speed-strength abilities.

Considering that the listed factors have a direct impact on the result of competitive activity, it was important to determine the degree of their influence on the strength abilities of athletes and the characteristics of muscle efforts that most influence the sporting achievements of armwrestlers of the specified weight.

Hypothetically, it was assumed that this may not be a large indicator of maximum strength, but other strength and speed-strength capabilities, such as explosive strength and strength endurance; in addition, it was important to establish the degree of influence of these qualities on the ability to demonstrate greater rapid strength and strength endurance.

There is very little research in this direction in speed-strength sports. Also, the listed problems are not sufficiently covered in the available sources of information (Coletta et al., 2022; Mao J-T et al., 2022); therefore the search for an answer regarding the determination of the characteristics of the manifestation of various characteristics of the manifestation of dynamic efforts of arm wrestlers is of particular importance for the theory and practice of sports.

It was also assumed that the absolute strength indicators of armwrestlers are not decisive in the effectiveness of a competitive match. Thus, in the works of Mazurenko (2019), it was noted that athletes with weaker strength indicators won the competition. Therefore, our research was aimed at studying both strength and speed-strength indicators, that is, the gradual development of different types of strength over time. The hypothesis turned out to be correct, which is confirmed by the results of the correlation analysis. Thus, out of 36 correlation indicators, the data of armwrestlers 1 and 2 have 11 modules with very high connection strength ( $r = 0.926-0.999$ ), of which 7 modules are with time and 4 are with force characteristics of efforts. Athletes 3 and 4 also have 3 modules with very strong connections ( $r = 0.916-0.948$ ) and 8 with strong connections ( $r = 0.739-0.886$ ), of which 7 modules are with strength indicators and 4 modules are related to time characteristics. That is, the first pair wins due to explosive strength, and the other two athletes due to strength endurance.

According to publications and the results of our research, dynamic force in the process of overcoming resistance is manifested through explosive, fast and slow force (Harčarik et al, 2020; Podrigalo et al., 2017). It has also been established that explosive force is characterized by two components: starting and accelerating force (Chang-Yk Lee et al., 2022). The starting force manifests itself from 100 to 200 ms and provides the speed of development of the working force at the initial moment of muscle tension (Coletta et al., 2022), which confirms our data. Thus, in all the athletes we studied, the speed-strength index appears at 200 ms of effort, regardless of the level of genetically determined abilities.

Armrestlers 1 and 2 with high speed-strength characteristics demonstrated significantly high results of starting and accelerating force, respectively,  $t = 3.92$ ;  $P < 0.05$  and  $t = 3.86$ ;  $P < 0.05$  at 200 ms and 300 ms force. The time to achieve maximum strength in these athletes is significantly less ( $t = 2.79$ ;  $P < 0.05$ ), and they also have a significantly better indicator of the force gradient ( $t = 3.69$ ;  $P < 0.05$ ) and the time to achieve strength in 1 kg ( $t = 3.14$ ;  $P < 0.05$ ). This pair of athletes is characterized by a harmonious ratio of strength and speed-strength characteristics of the effort between the left and right hands.

Armrestlers with predominant indicators of strength endurance are characterized by a higher indicator of maximum and relative strength, a significantly longer time to achieve maximum strength, as well as significantly higher indicators of strength and speed-strength index in the last

second of effort, respectively:  $t = 3.52$ ;  $P < 0.05$  and  $t = 5.45$ ;  $P < 0.01$ .

Separately, it can be noted that athletes with high speed-strength characteristics of effort are more titled and have more harmonious results with both left and right hands.

However, it should be noted that, due to the small size of the specialized sample, there is a risk of overinterpretation of the study results. It is important to note that while the results are relevant and have potential value for understanding the performance of elite armwrestlers, they may not be generalize to broader population or armwrestlers of varying fitness levels.

## Conclusions

The conducted research made it possible to reliably establish the degree of difference in the manifestation of efforts of armwrestlers with high rates of speed-strength characteristics of effort and athletes with high capabilities of strength endurance. Based on the results of the study, the features of the dynamics of the time and power characteristics of the efforts of highly qualified arm wrestlers weighing from 80 to 100 kg before achieving boundary efforts in competitive exercises were determined, as well as the significance of various characteristics of the manifestation of efforts on the success of results in competitive activities. Thus, analysis of the time and force characteristics of the manifestation of force in the process of achieving boundary resistance (maximum force) allows us to clearly establish the genetically determined speed and strength abilities for the manifestation of explosive, fast and slow strength of armwrestlers.

Further research will be aimed at experimentally substantiating the methodology for developing speed-strength capabilities (starting, explosive, fast, slow strength) for training from groups of initial training to groups of maximum capabilities, to which it is planned to attract a larger number of participants by age, weight and level of preparedness.

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## Conflict of interest

The authors declare no conflict of interest.

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## АНАЛІЗ Й ОЦІНКА ОСОБЛИВОСТЕЙ ПРОЯВУ ДИНАМІЧНОЇ СИЛИ У ПРОВІДНИХ АРМРЕСТЛЕРІВ СВІТУ

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

Реферат. Стаття: 10 с., 3 табл., 1 рис., 24 джерел

**Мета.** Визначення особливості прояву сили у змагальних вправах армрестлерів високої кваліфікації з різними силовими здібностями.

**Матеріал і методи.** У дослідженні взяли участь 4 кращих армрестлера світу вагою від 80 до 100 кг ( $m = 87,50 \pm 2,47$  кг) у 2017-2020 роках. Визначено чотири силові тестові вправи, що забезпечують виконання змагальної дії в армрестлінгу: згинання пальців, розгинання молотком, гак і згинання кисті. Силові показники у всіх тестових вправах вимірювали електротензодинамометром серії FL 1K 0,5N, 1000N, Kern & Sohn GmbH (Китай), закріпленим на столі для армрестлінгу за допомогою авторського блокового приладу.

**Результати.** Результати кореляційного аналізу взаємозв'язків між досліджуваними показниками підтверджують наявність різниці у спрямованості та силі взаємозв'язків між силовими та часовими характеристиками зусиль спортсменів із різними силовими та швидко-силовими здібностями. Так, з 36 показників кореляційного зв'язку дані армрестлерів 1 і 2 мають 11 модулів із дуже великою силою зв'язку ( $r = 0,926-0,999$ ), з яких 7 модулів із часовими та 4 з силовими характеристиками зусиль. У спортсменів 3 і 4 також є 3 модулі з дуже великою силою ( $r = 0,916-0,948$ ) і 8 – із сильними зв'язками ( $r = 0,739-0,886$ ), з яких 7 модулів із силовими показниками та 4 модулі пов'язані з часовими характеристиками. Але інші показники кореляційного зв'язку мають дуже слабкі ( $r < 0,29$ ) та слабкі ( $r = 0,3-0,5$ ) рівні взаємозв'язків.

**Висновки.** Аналіз часових і силових характеристик прояву сили у процесі досягнення межового опору (максимальної сили) дозволяє чітко встановити генетично обумовлені швидкісні та силові здібності до прояву вибухової, швидкої та повільної сили армрестлерів.

**Ключові слова:** армспорт, армрестлінг, армрестлери, вибухова сила, силові показники.

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ORIGINAL SCIENTIFIC ARTICLE

## RELATIONSHIP BETWEEN STANCE WIDTH VARIATION DURING ONE REPETITION MAXIMUM BARBELL HIP THRUST PERFORMANCE AND KICKING SPEED FOR YOUNG ELITE SILAT ATHLETES

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### Abstract

**Study purpose.** This study aimed to determine the relationship between kicking speed performance and different stance widths during barbell hip thrust (BHT) at one repetition maximum (1RM) scores among young elite Silat athletes.

**Materials and methods.** 15 male and 15 female Silat athletes with at least one year of resistance training experience and a mean age of  $21.3 \pm 1.2$  years participated in this study. The load indicator performance associated with kicking performance was measured using 1RM load during BHT at varying stance widths. The data was analyzed using Pearson correlation tests through the SPSS Version 25 application.

**Results.** A significant correlation was found between stance width, physical characteristics, and performance metrics with a low to moderate relationship. For physical features, weight ( $r = 0.43$ ,  $p < 0.05$ ), height ( $r = 0.64$ ,  $p < 0.05$ ), and leg length ( $r = 0.44$ ,  $p < 0.05$ ) show positive relationship. Low to moderate significant relationships were found during WSW-RFK ( $r = 0.39$ ,  $p < 0.05$ ) regarding 1RM and kicking performance. No significant correlations were found between NSW or NRW and the observed variables, except for a negative correlation between NRW and strength ( $r = -0.43$ ,  $p < 0.05$ ). There was a significant difference between males vs. females in RFK-NSW, RFK ( $p = 0.006$ ,  $p < 0.05$ ), and LFK-NRW ( $p = 0.001$ ,  $p < 0.05$ ) in kicking performance.

**Conclusions.** This study revealed that stance width in barbell hip thrusts moderately correlates with physical characteristics and performance in young elite Silat athletes, where wider stances align with physical characteristics and narrower stances align with lower kicking performance. It also highlighted the importance of personalized training due to observed gender differences in kicking speed.

**Keywords:** silat, barbell hip thrust, kicking, strength training, combat sport, stance width.

### Introduction

Silat is one of the combat sports that originates from South Asian countries. It combines grace, technique, and power to create an elegant yet practical form of self-defence and sport and has noble values (Lisdayanti et al., 2019; Shapie & Elias, 2016). This combat is becoming more and more known in the eyes of the world, and athletes' involvement in this competitive sport is becoming increasingly popular

with combat sports fans. Not only that, but the mark of Silat is also getting more and more attention among researchers to be tested. Research related to the sport of Silat has been started since 1983 (Eichberg, 1983), and since then, the positive development every year can be seen through the number of published articles.

Silat has been adapted from a self-defense art to a competitive sport in the modern world. This transformation requires a higher emphasis on physical aspects such as strength, flexibility, coordination, and endurance (Patah et al., 2021). The importance of physical adaptation activities in the sport of Silat is not limited to improving physical fitness alone but also involves improving technical and tactical

performance in complex movements such as attacking, defending, and avoiding. Through intensive training, Silat athletes can develop quick reactions and precision in movements that support competition strategies. These aspects create a competitive Silat athlete who reflects a unique blend of tradition, art, and sports science (Apriantono et al., 2020; Aziz et al., 2002). In addition, it is worth noting that the art of Silat encompasses a diverse range of attacking and defending strategies, with a particular emphasis on using kicking techniques.

This kind of combat sport heavily relies on kicking techniques. Kicking allows athletes to strike their opponents effectively and provides them with various strategic advantages. The importance of kicking in combat sports stems from its effectiveness as an offensive and defensive technique, its ability to create distance and control space, and impact on scoring in competitive matches (Ruzbarsky et al., 2022). The velocity of kicking, expressly, assumes a crucial role in the efficacy and productivity of these actions. In the field of competitive Silat, having the ability to execute fast and forceful kicks holds substantial influence over an athlete's victory.

For several reasons, kicking is essential to Silat and other combat sports. Firstly, the force or velocity of a kick delivered by an athlete is crucial in determining their exceptional fitness. The power generated by a lift is a critical factor in an athlete's overall performance and directly impacts their ability to score points or defeat their opponents. Secondly, using kicks expands the target area for athletes, giving them a greater chance to score points or hinder their opponents. This leads to the differences between winning and losing factors in combat sports settings (Soo et al., 2018). Within the broader framework of sports performance, strength has become acknowledged as a critical determinant in improving kicking techniques.

Strength and conditioning are significant attributes that influence athletic performance across various disciplines, including but not limited to track and field, weightlifting, and different combat sports. Strength training, an indispensable aspect of an athlete's regimen, holds the utmost significance in bolstering kicking power in combat sports (Barley et al., 2019; Da Silva et al., 2015). This form of training explicitly strengthens the leg muscles that are put to work while executing a kick. Stronger muscles equate to more potent kicks, enhancing the range and effectiveness of this crucial combat sport technique. Furthermore, strength training also plays a pivotal role in improving an athlete's balance and coordination, which is crucial when delivering powerful and efficient kicks. Therefore, neglecting strength training could inevitably result in diminished kick performance, thus underscoring its fundamental role in combat sports.

The barbell hip thrust (BHT) is emerging as a crucial exercise for enhancing lower limb power, a vital component in kick-based martial arts like Silat. BHT has been widely used in strength and conditioning programs worldwide (Contreras et al., 2011; Ronai, 2021). Additionally, BHT is one type of horizontal loaded movement contributing to the horizontal direction in specific actions. These exercises have been shown to outperform machine exercises regarding muscle activation. According to Contreras et al. (2011), the barbell hip thrust is a loaded bridging exercise that targets the hip extensor musculature against barbell resistance, leading to improved speed, horizontal force production, and gluteus maximus hypertrophy. Several studies have found

the potential benefits of BHT on sports performance. For example, 6 to 8 weeks of training does improve sprint time (Dello Iacono et al., 2018) and increment in jump performance (B. Zweifel et al., 2017). A positive correlation was also found between BHT and post-activation performance in a change of direction (G. Lockie et al., 2020). Despite the potential benefits of barbell hip thrusts in enhancing lower limb power, there is a lack of research examining the application of this exercise in Silat. Even more concerning is the near absence of research studies investigating the application of strength training, particularly barbell hip thrusts, in Silat, a traditional martial art form with a rich cultural history and growing international recognition.

One parameter that can be manipulated during strength training exercises is the position of feet for various stance widths. Stance width during exercises like the BHT can significantly influence the athlete's kicking performance (Asayama et al., 2021; Lahti et al., 2019). Additionally, mastering various stance widths during exercise can improve an athlete's versatility, providing them with the adaptability to deliver an array of kicks with diverse strength profiles. Furthermore, stance exploration helps develop an athlete's understanding of their body mechanics and muscle activity, enabling them to generate maximum force during a kick. The significance of stance width and BHT exercise has been firmly established in several scopes of performance in sports (Hawkins & Sefton, 2011; Otsuka et al., 2021; Rajinikumar, 2019). For example, a study by Mohd Nasir et al. (2023) found an improvement in power and velocity-related performance in kicking when applying narrow stance width during barbell hip thrust exercise among adolescent Silat's athletes. However, exploring its use within the distinctive context of Silat has not been thoroughly investigated, and more study needs to be conducted. The current information gap poses a noteworthy study prospect, as it has the potential to unveil unique associations between strength training and combat sports performance. Thus, the present study aims to fill this research interest by examining the relationship between barbell hip thrust scores during stance widths and kicking speed in young elite Silat athletes. This investigation has the potential to provide new perspectives on improving Silat's performance.

## Materials and Methods

### Participants

This study used purposive sampling among elite young athletes selected from the state level. A total of 30 elite young athletes (15 male and 15 female) were selected. The participants were free from any diseases or injuries during testing. All participants had participated in competitive Silat competitions for at least five years before the study. They were actively involved in Silat and performance training during testing. The participants were the best elite young Silat athletes representing the state at the National level.

### Procedures

The study was structured across four testing sessions, with a 72-hour rest interval instituted between each session to mitigate carryover effects. The initial session was conducted

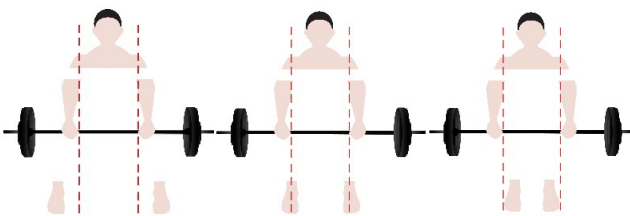
for demographic data collection, including metrics such as weight, height, and years of experience in Silat and strength training. Subsequently, an expert trainer introduced participants to the BHT technique with the inclusion of the various types of stance width – namely, wider than shoulder width (WSW), normal shoulder width (NSW), and narrower than shoulder width (NRW). After the introductory session, the athletes were crossover-randomly assigned to one of three groups based on stance width.

During the introductory session, 1RM procedures were performed to set the weight for the testing session. A general warm-up session was conducted to ensure that the athletes were adequately prepared for the 1-RM tests and to minimize the risk of injury. This was followed by a series of 3 set x 8-10 repetitions with 40% 1RM, 8 repetitions of 50% 1RM, and 6 repetitions of 60% 1RM, with a minimal 5-minute rest between sets. This is to ensure that participants were adequately rested before performing the 1RM of BHT as the final load and repetition to be used as the performance score for this study. The procedures were followed based on guidelines set forth by the National Strength and Conditioning Association (NSCA) (Larsen et al., 2021).

### Stance Width

Three different stands were measured in this study (Wider than shoulder width (WSW), Normal shoulder width (NSW), and Narrow than shoulder width (NRW)). Table 1 shows the different types of stance widths. Subjects were cross-over, randomized, and assigned according to the difference in stance width. For wider than shoulder width, subjects will put their feet approximately 10cm outside from the acromioclavicular joint with the toes pointing forward. Meanwhile, the subject will put their feet about 10cm inside the body from the acromioclavicular joint for the narrow stance width. Lastly, with normal shoulder width, the feet will be standing directly the same with the shoulder width in line with the acromioclavicular joint.

**Table 1.** Type of Stance width

| Wider than Shoulder Width (WSW)                                                    | Normal shoulder width (NSW)                       | Narrow than shoulder width (NRW)                                            |
|------------------------------------------------------------------------------------|---------------------------------------------------|-----------------------------------------------------------------------------|
|  |                                                   |                                                                             |
| Approximately 10cm outside the acromioclavicular joint                             | Directly in line with the acromioclavicular joint | Approximately 10cm inside towards the body from the acromioclavicular joint |

### Barbell Hip Thrust

The BHT was chosen as the primary exercise metric due to its efficacy in targeting the posterior chain, which is crucial for kicking performance in Silat. During the BHT, participants were guided to elevate the barbell to a predetermined height in each trial, facilitating consistency across attempts. The athletes were positioned with their upper backs against a flat bench, and their feet were placed according to the specific stance width assigned (WSW, NSW, or NRW) while making sure the toes were pointed forward. A barbell pad was used at the crease of their hips to alleviate discomfort. Throughout the execution of the thrust, participants maintained a neutral spine and pelvis. They were provided with real-time, continuous feedback by expert trainers to ensure no tilting of the barbell occurred at its apex, thereby maintaining the integrity of the movement.

### Kicking performance

Kicking movements represent a critical aspect of performance in Silat; thus, capturing accurate data was imperative. For this purpose, a high-resolution iPad Pro 11-inch (3rd generation) was employed to record the athletes' kicks. In this study, the front kick for the right and left was measured for each participant. After the recording, the video was imported into the Kinovea application, a specialized sports science motion analysis software. Kinovea's robust feature set allowed for a frame-by-frame breakdown of each video, enabling precise calculation of kicking speed. This technology provided qualitative and quantitative data, enriching the performance analysis's comprehensiveness.

### Data Analysis

The data was analysed using descriptive statistics, and Pearson correlation was used to study the relationship between stance width during BHT, physical traits, and kicking performance. Statistical significance was set at  $p < 0.05$ , and all analyses were conducted using SPSS software version 25 (IBM, New York, USA).

### Ethical approval

The procedures for involving human subjects were conducted per the applicable national rules and institutional protocols. They were consistent with the principles outlined in the Declaration of Helsinki. In addition, the authors obtained approval from the institutional review boards associated with their respective institutions. Each participant who participated in the research had read and signed the informed consent form approved by the Ethics Committee of Sultan Idris Education University (code 2021-0224-01).

In this study, all participants involved have provided informed consent.

### Results

Table 2 presents the demographic data of the participants' physical characteristics for this study. Significant differences existed between the weight, height, and length of the participant's legs but contradicted the results for age, years of Silat experience, and years of strength training experience.

**Table 2.** Descriptive of physical characteristics of the athletes

| Variable         | Combine<br>(mean ± SD) | Male<br>(mean ± SD) | Female<br>(mean ± SD) | Male vs Female |
|------------------|------------------------|---------------------|-----------------------|----------------|
| Age (years)      | 20.8 ± 2.2             | 21.1 ± 2.2          | 20.5 ± 2.3            | 0.47           |
| Weight (kg)      | 61.1 ± 17.6            | 68.9 ± 20.2         | 53.2 ± 10.4           | 0.01*          |
| Height (cm)      | 166.2 ± 9.7            | 173.9 ± 5.8         | 158.5 ± 5.9           | 0.001*         |
| Silat (years)    | 6.2 ± 2.4              | 5.6 ± 2.2           | 6.7 ± 2.7             | 0.24           |
| Strength (years) | 4.2 ± 2.4              | 4.2 ± 1.9           | 4.3 ± 2.2             | 0.41           |
| Leg length (cm)  | 91.2 ± 7.7             | 95.3 ± 6.4          | 87.1 ± 6.7            | 0.002*         |

\*Significant value ( $p < 0.05$ )

**Table 3.** Summary of 1RM BHT scores

| Variable | Combine<br>(mean ± SD) | Male<br>(mean ± SD) | Female<br>(mean ± SD) | Male vs Female |
|----------|------------------------|---------------------|-----------------------|----------------|
| WSW      | 107.9 ± 22.3           | 124.2 ± 13.5        | 91.60 ± 16.5          | 0.001*         |
| NSW      | 109.2 ± 26.8           | 109.4 ± 22.1        | 109.0 ± 31.6          | 0.96           |
| NRW      | 105.7 ± 21.8           | 105.6 ± 20.9        | 104.5 ± 23.4          | 0.89           |

\*WSW= wider than shoulder width, NSW= normal shoulder width, NRW=narrow than shoulder width, significant value ( $p < .05$ )

**Table 4.** Summary of Front Kick Performance

| Variable | Combine<br>(mean ± SD) | Male<br>(mean ± SD) | Female<br>(mean ± SD) | Male vs Female |
|----------|------------------------|---------------------|-----------------------|----------------|
| RFK- WSW | 3.36 ± 0.97            | 3.63 ± 1.2          | 3.09 ± 0.6            | 0.13           |
| LFK-WSW  | 3.11 ± 0.97            | 3.37 ± 1.14         | 2.86 ± 0.73           | 0.15           |
| RFK-NSW  | 3.36 ± 1.05            | 3.84 ± 1.04         | 2.88 ± 0.74           | 0.001*         |
| LFK-NSW  | 3.19 ± 1.11            | 3.54 ± 1.33         | 2.84 ± 0.72           | 0.08           |
| RFK-NRW  | 3.48 ± 1.10            | 4.01 ± 1.26         | 3.03 ± 0.73           | 0.006*         |
| LFK-NRW  | 3.22 ± 1.08            | 3.93 ± 0.94         | 2.48 ± 0.62           | 0.001*         |

\*RFK-WSW=right front kick wider than shoulder width, LFK-WSW=left front kick wider than shoulder width, RFK-NSW=right front kick normal shoulder width, LFK-NSW=left front kick normal shoulder width, RFK-NRW=right front kick narrow than shoulder width, LFK-NRW=left front kick narrow than shoulder width.

There were significant differences between males vs. females for weight ( $p = 0.01$ ,  $p < 0.05$ ), height ( $p = 0.001$ ,  $p < 0.001$ ), and leg length ( $p = 0.002$ ,  $p < 0.05$ ).

Table 3 summarises the load scores of 1RM at different types of stance widths while performing the BHT exercise. In the combined group, the average strength for WSW was found to be  $107.9 \pm 22.3$  kg. However, males exhibited significantly higher strength ( $124.2 \pm 13.5$  kg) than females ( $91.60 \pm 16.5$  kg). The difference is statistically significant with a p-value of 0.001, indicating that males have a higher strength advantage in WSW stance than females. There were no significant differences in strength between males and females for the NSW and NRW stance widths. In NSW, males ( $109.4 \pm 22.1$  kg) and females ( $109.0 \pm 31.6$  kg) had similar mean strengths, with a p-value of 0.96. Similarly, in the NRW stance, males ( $105.6 \pm 20.9$  kg) and females ( $104.5 \pm 23.4$  kg) had closely aligned mean strength values, with a p-value of 0.89.

Meanwhile, Table 4 summarises the front kick performance recorded during the data collection. There were significant differences in right-front kick during WSW (RFK-WSW), right-front kick during NRW (RFK-NRW) and left-front kick during (LFK-NRW). No significant difference was found for both legs during NSW and left-front kicks during WSW (LFK-WSW). There was a significant difference between males vs. females during RFK-NSW

( $p = 0.001$ ,  $p < 0.001$ ). For the NRW stance, both RFK ( $p = 0.006$ ,  $p < 0.05$ ) and LFK ( $p = 0.001$ ,  $p < 0.001$ ) showed significant differences when comparing males vs. females.

Table 5 presents a correlation analysis highlighting the distinctive relationships between 1RM scores in different stance widths, physical characteristics, and front kick performances. The WSW stance shows significant positive correlations with height ( $r=0.64$ ), weight ( $r=0.43$ ), and leg length ( $r=0.44$ ), as well as with right front kick (RFK) performance ( $r=0.39$ ). However, NSW and NRW stances exhibit weaker and non-significant correlations with these physical characteristics. Notably, a negative correlation exists between NRW 1RM and strength training ( $r=-0.42$ ). These numerical values provide a clear understanding of the strength of the correlations observed in the study.

## Discussions

This study investigated the correlation between 1RM scores during barbell hip thrusts across different stance widths and front kick performance in young Silat athletes. The kicking performance was measured for right and left front kicks. The study's major finding revealed a low to moderate correlation between the measured variables (BHT vs Kicking performance) for all stance types.

**Table 5.** Correlation analysis between 1RM scores during stance width vs. Physical Characteristic and Front Kick Performance

| Variable | Correlation value (r) |        |        |       |          |            |       |       |
|----------|-----------------------|--------|--------|-------|----------|------------|-------|-------|
|          | Age                   | Weight | Height | Silat | Strength | Leg length | RFK   | LFK   |
| WSW      | 0.14                  | 0.43*  | 0.64** | -0.09 | 0.04     | 0.44*      | 0.39* | 0.16  |
| NSW      | -0.06                 | -0.14  | -0.41  | 0.07  | -0.26    | -0.06      | 0.16  | -0.19 |
| NRW      | -0.05                 | -0.25  | -0.14  | -0.12 | -0.42*   | 0.14       | -0.19 | -0.01 |

\*WSW= wider than shoulder width; NSW= normal shoulder width; NRW=narrow than shoulder width; RFK= right front kick; LFK= left front kick; significant value ( $p < .05$ )

There are significant physical differences between male and female athletes regarding weight, height, and leg length. The data suggests that male athletes tend to have a higher 1RM in a WSW stance ( $124.2 \pm 13.5$ ) than females ( $91.60 \pm 16.5$ ), indicating a gender-specific advantage or preference for this stance in maximizing strength. This difference in performance could be attributed to physiological differences or training adaptations that favour males in wider stance positions. Interestingly, NSW and NRW stances do not show such pronounced gender disparities, suggesting a more uniform potential for strength development across these stances. The current study's findings contradict those of a previous study on gender preferences. According to Kittilsen et al. (2021), both genders showed similar improvement relative to their one-rep maximum (1RM) during four sets of four repetitions of leg press exercise at 85-90%. However, the differences between the maturity and chronological age of the sample during the current study and the previous study affect the result.

Moreover, the results indicated a significant relationship only in the case of the WSW stance with kicking performance compared to the other two stances, namely, NSW and NRW. The significant differences ( $p < .001$ ) only can be seen between males and females in the WSW stance. This finding is interesting as stance width is often considered an essential factor in the execution of kicks, as it can affect balance, stability, and power generation during the kicking motion (Larsen et al., 2021; Lorenzetti et al., 2018). However, the results of this study suggest that in the specific context of barbell hip thrusts and their relationship to kicking speed, stance width does not play a significant role. One possible explanation could be that the barbell hip thrust exercise focuses primarily on hip extension strength and power rather than the specific mechanics of the kicking motion (Ronai, 2021). Conversely, any lower limb exercise with hip extension movement should have a transferrable effect into specific action during the traditional practices. This did not happen for this population during this study, contradicting the previous research. Lahti et al., (2019) found a significant difference between narrow and wide stance performance for sagittal and frontal plane motion.

As in this case, the kicking action involves these two planes of motion. This is the first study to examine the effect of barbell hip thrust associations on kicking performance for different types of stance width for combat sports. Another setting of lower limb exercise on different stance widths showed significant improvement in terms of muscle activity during wide stance in Romanian deadlift (Koderi et al., 2020), which focuses more on external knee movement,

which involves more bicep femoris activated, as this is also one of the significant muscle contributions during in kicking action. Gender preferences in barbell hip thrust studies have not been extensively researched. However, the few studies conducted align with prior recommendations (Contreras et al., 2016). Furthermore, differences in torso structure between genders should also be considered, as broader male shoulders may exhibit different movement patterns compared to narrower female shoulders. This suggests that inherent differences in shoulder width between males and females could impact the execution and biomechanics of exercises such as the barbell hip thrust. Additionally, this study is the first known comparison of males and females in Silat and combat sports studies, specifically using barbell hip thrust as an exercise parameter.

Another observation from the current study is that the study found a low to moderate association between 1RM of WSK-RFK exercise. In contrast, a low negative correlation was observed during NSW-LFK and both NRW-RFK and NRW-LFK. This finding suggests that as the load increased during the exercise, there was a decrease in kicking speed among the young elite Silat athletes. This intriguing finding raises questions about the relationship between strength training and explosive movements such as kicking. It is well known that strength training can improve power and force production, which are essential factors in generating explosive moves like kicks in combat sports (Subekti et al., 2020). The intersection of barbell hip thrust exercises with kicking performance in combat sports remains a largely uncharted domain in the existing literature. Historically, sports science has emphasized understanding how foundational lower body exercises influence generic athletic outputs. For instance, the classic squat has been extensively researched for its potential to boost vertical jump and sprint performance (Atalağ et al., 2020; Chelly et al., 2009). Nevertheless, the current research uniquely bridges the gap in the literature by focusing on the barbell hip thrust exercise, which still needs to be represented in sports science research.

## Conclusions

In conclusion, this research contributes valuable insights into the role of strength training, specifically BHT, in enhancing kicking speed among Silat athletes. Overall findings indicate a low to medium correlation between strength during BHT and the variety of stance width on kicking performance among young Silat athletes. The findings underscore the potential benefits of incorporating BHT exer-

cises with varying stance widths into martial artists' training regimens to optimize their kicking performance. Future research might delve deeper into other types of kicking, such as sidekicks, roundhouse kicks, back kicks, etc. Manipulation of load and repetition also should be investigated to see the differences among the Silat athletes. Application BHT on various levels of Silat athletes and genders also provides training options for lower limb intervention. The effect of BHT can also be explored on jumping performance in Silat athletes, which power element contributes to in attacking and defending techniques in Silat settings.

## Conflict of interest

The authors state no conflict of interest during this study.

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## ВЗАЄМОЗВ'ЯЗОК МІЖ ВАРІЮВАННЯМ ШИРИНИ СТІЙКИ ПІД ЧАС ВИКОНАННЯ ВПРАВИ З ПІДЙОМУ СТЕГОН ЗІ ШТАНГОЮ ЗА ОДНЕ ПОВТОРЕННЯ З МАКСИМАЛЬНОЮ ВАГОЮ ТА ШВИДКІСТЮ УДАРІВ НОГАМИ В МОЛОДИХ ЕЛІТНИХ СПОРТСМЕНІВ ІЗ СИЛАТУ

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

Реферат. Стаття: 8 с., 5 табл., 29 джерел.

**Мета дослідження.** Метою цього дослідження було визначити взаємозв'язок між показниками швидкості ударів ногами та різною шириною стійки під час виконання вправи з підйому стегон зі штангою з положення лежачи з упором верхньої частини тулуба на лавку («Сідничний міст») за одне повторення з максимальною вагою (1ПМ) серед молодих елітних спортсменів із силату.

**Матеріали та методи.** У цьому дослідженні взяли участь 15 спортсменів і 15 спортсменок із силату з досвідом тренувань зі спротивом щонайменше один рік і середнім віком  $21,3 \pm 1,2$  року. Ефективність показників навантаження, пов'язаних з ефективністю ударів ногами, вимірювали з використанням максимального навантаження за одне повторення (1ПМ) під час виконання вправи «Сідничний міст» за змінної ширини стійки. Аналіз даних проводили з використанням коефіцієнтів кореляції Пірсона на програмному забезпеченні SPSS версії 25.

**Результати.** Було виявлено статистично значущу кореляцію між шириною стійки, фізичними характеристиками та показниками продуктивності зі зв'язком від низького до середнього ступеня. Стосовно фізичних характеристик, позитивний зв'язок демонструють вага ( $r = 0,43$ ,  $p < 0,05$ ), зріст ( $r = 0,64$ ,  $p < 0,05$ ) і довжина ніг ( $r = 0,44$ ,  $p < 0,05$ ). Під час аналізу кореляції WSW-RFK («ноги ширше плечей» – «прямий удар правою ногою») ( $r = 0,39$ ,  $p < 0,05$ ) було виявлено статистично значущі зв'язки від низького до середнього ступеня стосовно 1ПМ та ефективності ударів ногами. Між стійкою NSW («ноги на ширині плечей») або NRW («ноги вужче плечей») і спостережуваними змінними значущих кореляцій виявлено не було, за винятком негативної кореляції між стійкою NRW («ноги вужче плечей») і силою ( $r = -0,43$ ,  $p < 0,05$ ). Спостерігалася статистично значуща різниця між чоловіками та жінками в ефективності ударів ногами за показниками RFK-NSW («прямий удар правою ногою» – «ноги на ширині плечей»), RFK («прямий удар правою ногою») ( $p = 0,006$ ,  $p < 0,05$ ) та LFK-NRW («прямий удар лівою ногою» – «ноги вужче плечей») ( $p = 0,001$ ,  $p < 0,05$ ).

**Висновки.** Це дослідження показало, що ширина стійки під час виконання підйому стегон зі штангою середньою мірою корелює з фізичними характеристиками та результативністю молодих елітних спортсменів із силату, де ширші

стійки відповідають фізичним характеристикам, а вужчі стійки – нижчій результативності ударів ногами. У ньому також підкреслюється важливість індивідуалізованого тренування через спостережувані гендерні відмінності у швидкості ударів ногами.

**Ключові слова:** силат, підйом стегон зі штангою, удари ногами, силове тренування, єдиноборство, ширина стійки.

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ORIGINAL SCIENTIFIC ARTICLE

## TRANSFORMING KEMPO FITNESS: ENHANCING PHYSIOLOGICAL RESPONSES AND PHYSICAL PERFORMANCE IN ADOLESCENTS VIA A TABATA-BASED METHOD

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### Abstract

**Study purpose.** Examining the physiological and physical effects of Tabata training with Kempo sports movement techniques.

**Materials and methods.** The study participants were 16 adolescents divided into two distinct groups: the Tabata group and the non-Tabata group. The training was conducted for 6 weeks, 3 times per week, with each session lasting 2 hours. The training components for kicks and punches included Gyaku Geri, Jun Mawashi Geri, Jun Zuki, and Gyaku Mawashi Geri. Each teenager did physical exercise once a week for 2 hours. A normality test (Shapiro-Wilk) was used to assess the normality of the data. A Two-Way ANOVA with a significance level of less than 0.05 was conducted to examine the difference in means between the two groups. Furthermore, the researchers also tested the N-Gain Score to assess the effectiveness of the 6-week Tabata training program. All tests were conducted using SPSS version 23 and GraphPad Prisma version 10 for graph creation.

**Results.** The statistics indicate that a 6-week training with Tabata can effectively reduce resting heart rate and improve Standing Broad Jump (SBJ) performance by a value of sig. <0.05. In the pretest-posttest difference test within the group, the results show sig. <0.05. The results of the N-Gain Score test show that Kempo training using the Tabata method is effective in reducing resting heart rate by up to 88%, but is not effective in increasing power (SBJ) by a value of 10%.

**Conclusions.** The study revealed that incorporating the Tabata method into Kempo training, with necessary adjustments for 6 weeks, led to a notable reduction in resting heart rate. A decrease in resting heart rate is a dependable indicator of the advancement in physical fitness and general well-being in adolescents.

**Keywords:** Tabata, resting heart rate, modification.

### Introduction

The physical fitness of an individual is closely related to their ability to perform daily physical activities (Aslan et al., 2019; Vukasevic et al., 2019). Consistent physical activity yields health advantages, specifically by enhancing physical fitness (Warburton & Bredin, 2016, 2017, 2018), and can improve vascular function (Black et al., 2008; Mora et al., 2007; Moriguchi et al., 2005). However, the benefits obtained

depend on the individual's fitness level, age, and training intensity (Vina et al., 2012).

Mutohir et al (Mutohir et al., 2022, 2023) said in their research entitled "National Sports Development Index Report for 2021 and 2022" that today's fitness level is still quite low for teenagers in Indonesia. Someone who has low fitness is at risk of getting sick easily (Bratland-Sanda et al., 2020; Kakanis et al., 2010), such as cardiovascular disease, obesity, hypertension and hyperglycemia (Fornoni & Raji, 2005). The risk of cardiovascular disease that teenagers today have is due to lifestyle changes such as lack of activity, which causes lack of movement, stress and consuming unhealthy foods (Snel et al., 2022).

Sacher and Cable's research (Sacker & Cable, 2006) stated that having high fitness during adolescence positively impacts health later in life (Moliner-Urdiales et al., 2010; Silventoinen et al., 2021). The World Health Organization (WHO) recommends that teenagers exercise at least 60 minutes at moderate intensity (Chaput et al., 2020). Various studies show that physical activity has a good impact, namely reducing depression, improving cognitive function and improving mood (Penedo & Dahn, 2005).

To increase your fitness level, you need to do high-intensity interval training (HIIT) (Hottenrott et al., 2012); HIIT has also been proposed as an exercise that can save time in daily activities (Helgerud et al., 2007; Milanović et al., 2015; Ramos et al., 2015). Please note that there are several studies that say using HIIT training can improve aerobic fitness ( $VO_{2max}$ ) (Cocks et al., 2013; Keteyian et al., 2008; McRae et al., 2012) dan anaerobic (Whyte et al., 2010). The intensity used in aerobic HIIT training is around 85% to 95% of the maximum heart rate (Gibala et al., 2012; Weston et al., 2014; Wisløff et al., 2007). Meanwhile, the frequency of HIIT training done 3 days/week with moderate to high intensity can increase a person's maximum aerobic strength (Garber et al., 2011) so that it can result in an increase in maximum oxygen supply in the endurance system.

Currently, teenagers are more motivated to do a physical activity based on the type of sport (Molanorouzi et al., 2015), and combat sports are one of the sports that people are interested in apart from team sports such as football and basketball. On the other hand, an individual's inability to carry out physical activities due to limited time in carrying out physical activities (Koh et al., 2022) is another obstacle to the decline in adolescent physiological components. In this study, researchers examined the use of Tabata training methods combined with martial arts sports movement techniques (Kempo) in improving the physiological and physical components of adolescents. In previous research (Akcan et al., 2021; Mischenko et al., 2021; Patah et al., 2021), Tabata training uses a lot of functional training and weight training. However, there has been no research that has studied further whether movement and punch technique training using the Tabata method can improve cardiorespiratory.

Tabata is one of the most efficient HIIT training methods (Tabata, 2019). The Tabata protocol is characterized by 8 repetitions with 20 seconds of work and 10 seconds of rest performed in 8 sets (Tabata, 2019). The research of Menz et al. and Popowczak et al. (Menz et al., 2019; Popowczak et al., 2022) states that doing Tabata training with an intensity of 70%-80% of your maximum heart rate will get health benefits.

*The aim of this study* was to identify the effects of Tabata training modified with Kempo sports movement techniques on physiological and physical responses. According to researchers, this research uses the Tabata training method and combines movements from one sport, which is something new that has not been researched and developed, so it is necessary to research the success of this new method in increasing aerobic and anaerobic capacity.

## Materials and methods

### Study participants

Sixteen teenagers participated in this research; they had an average age of 19-20 years when this research was carried

out. Participants were characterized by only doing physical activity once a week with an average of 2 hours of exercise per week. Participants were divided into 2 groups, namely 8 teenagers in the Tabata group and 8 teenagers in the non-Tabata training group.

**Table 1.** Sample characteristics

|                          | Tabata     | Non-Tabata |
|--------------------------|------------|------------|
| Age (years)              | 20.00±2.27 | 19.60±1.41 |
| Body Weight (Kg)         | 54.13±8.03 | 58.63±10.9 |
| Body height (m)          | 1.66±0.06  | 1.60±0.07  |
| IMT (Kg/m <sup>2</sup> ) | 19.22±2.39 | 22.21±3.97 |

### Study organization

The Tabata group will do the exercises as in table 2 with a pulse intensity of 75% - 85% of the maximum pulse with a work:rest ratio of 20:10 seconds in 4 minutes for up to 6 training sessions, resting for 3 minutes each session while the non-tabata group will do Kempo training for 2 hours.

When assessing physical condition, researchers used Push-ups, Standing Board Jump (SBJ) and also the Multi Fitness Test (MFT) and these exercises had to be carried out until the sample was exhausted to measure upper and lower body strength and endurance.

### Push-up

This research used 90° push-up for protocol from (Hashim et al., 2018) for push up 30 seconds. In order to perform the 90° push-up, the test subject was required to lie face down on the floor with their hands beneath their shoulders, fingers pointing forward, and elbows positioned backward along the sides of their body. In the up position, the individual supported their body weight with their hands and toes while pushing themselves to full arm extension. The participant then lowered herself until her entire body, from the chest to the thighs, made contact with the floor while maintaining a straight posture. The participant then returned to the up position by pushing up to full arm extension. These ups and downs constituted one push-up test at 90 degrees. The subject of the test proceeded with these steps without pause until they became fatigued. A push-up test consisting of one 90-degree turn was recorded as the subject transitioned from the up position to the down position and back to the up position. The score was determined by the quantity of accurately performed 90-degree push-up tests prior to cessation or alteration of body position (Wood & Baumgartner, 2004).

### Standing Board Jump (SBJ)

The broad jump test while standing was conducted on a hard surface. The participants maintained a parallel stance with their feet parallel to the starting line and their heels on the line. Subsequent to receiving instructions from the investigator, the participants were required to execute a horizontal jump of maximum distance. Since neither the movement of the arms nor the legs had been specified, the participants were free to execute a self-determined depth

countermovement of the legs and a free-arm amplitude swing. The contestants were required to land with both feet jointly and halt the jump without making any additional progress. Each experiment was conducted in triplicate, with a five-minute interval between each iteration. The distance from the starting line to the heel of the foot closest to the starting line was measured in centimeters using a measuring tape. The highest score obtained from the three attempts was retained for further analysis (Thomas et al., 2020).

#### *Multi-stage Fitness Test (MFT)*

Test of Multi-Stage Fitness (MSFT) Participants in the MSFT run a series of 20-meter shuttle runs until they become exhausted (Ramsbottom et al., 1988). Beginning at

8.5 km/h, the MSFT accelerates by 0.5 km/h for every one-minute stage that is finished. Before the test began, each participant received a Polar Verity Sense heart rate monitor, which was used to track their heart rate in real time during the entire test. Encouragement was given verbally to make sure that participants worked until they were completely exhausted. The MSFT running distance served as the criteria measure.

#### *Lactate*

Blood lactate measurements were taken using the accutrend plus roche device. the measurement was carried out at the time after performing the MFT test before and after the 6-week training program ended. Measurement

**Table 2.** 6-week Tabata Kempo training program

|            |            | Sesi 1  | Sesi 2  | Sesi 3  | Sesi 4  | Sesi 5  | Sesi 6  |
|------------|------------|---------|---------|---------|---------|---------|---------|
| Repetisi 1 | 20 Seconds | Punch A | Punch B | Punch A | Punch B | Punch A | Punch B |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 2 | 20 Seconds | Kick A  | Kick B  | Kick A  | Kick B  | Kick A  | Kick B  |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 3 | 20 Seconds | Punch A | Punch B | Punch A | Punch B | Punch A | Punch B |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 4 | 20 Seconds | Kick A  | Kick B  | Kick A  | Kick B  | Kick A  | Kick B  |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 5 | 20 Seconds | Punch A | Punch B | Punch A | Punch B | Punch A | Punch B |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 6 | 20 Seconds | Kick A  | Kick B  | Kick A  | Kick B  | Kick A  | Kick B  |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 7 | 20 Seconds | Punch A | Punch B | Punch A | Punch B | Punch A | Punch B |
| Rest       | 10 Seconds | Rest    | Rest    | Rest    | Rest    | Rest    | Rest    |
| Repetisi 8 | 20 Seconds | Kick A  | Kick B  | Kick A  | Kick B  | Kick A  | Kick B  |

Note: Punch A = Gyaku Geri; Kick A = Jun Mawashi Geri; Jun Zuki = Punch B; Gyaku Mawashi Geri = Kick B

**Table 3.** Normality Test

| Variable                        |      | Tabata       |    |      | Non-Tabata |    |      |
|---------------------------------|------|--------------|----|------|------------|----|------|
|                                 |      | Shapiro-Wilk |    |      |            |    |      |
|                                 |      | Statistic    | df | Sig  | Statistic  | df | Sig  |
| Resting Heart (beat/minutes)    | Pre  | 0.97         | 8  | 0.88 | 0.91       | 8  | 0.33 |
|                                 | Post | 0.92         | 8  | 0.40 | 0.89       | 8  | 0.24 |
| Standing Board Jump (cm)        | Pre  | 0.97         | 8  | 0.92 | 0.92       | 8  | 0.44 |
|                                 | Post | 0.96         | 8  | 0.83 | 0.90       | 8  | 0.32 |
| Lactate (mg/dL)                 | Pre  | 0.89         | 8  | 0.23 | 0.90       | 8  | 0.28 |
|                                 | Post | 0.90         | 8  | 0.32 | 0.89       | 8  | 0.24 |
| VO <sub>2</sub> max (ml/kg/min) | Pre  | 0.89         | 8  | 0.24 | 0.96       | 8  | 0.80 |
|                                 | Post | 0.86         | 8  | 0.12 | 0.97       | 8  | 0.90 |
| Push Up (30 Second)             | Pre  | 0.90         | 8  | 0.27 | 0.92       | 8  | 0.47 |
|                                 | Post | 0.90         | 8  | 0.26 | 0.79       | 8  | 0.02 |

**Table 4.** The present study examines the mean changes in physiological and physical parameters following a six-week training intervention

| Variable                        |      | N | Mean±SD      | Min  | Max  | Mean±SD<br>Pre-Post | Sig.   |
|---------------------------------|------|---|--------------|------|------|---------------------|--------|
| Tabata                          |      |   |              |      |      |                     |        |
| Resting Heart (beat/minutes)    | Pre  | 8 | 85.25±12.03  | 70   | 108  | 23.00±14.57         | 0.003* |
|                                 | Post |   | 62.25±10.61  | 48   | 78   |                     |        |
| Standing Board Jump (cm)        | Pre  | 8 | 191.50±29.94 | 151  | 238  | 7.87±3.48           | 0.000* |
|                                 | Post |   | 199.40±29.65 | 161  | 244  |                     |        |
| Lactate (mg/dL)                 | Pre  | 8 | 10.36±3.11   | 6.2  | 14.7 | 3.38±1.69           | 0.001* |
|                                 | Post |   | 13.75±2.30   | 9.3  | 16.8 |                     |        |
| VO2max (ml/kg/min)              | Pre  | 8 | 36.60±4.07   | 30.6 | 41.5 | 2.87±1.70           | 0.002* |
|                                 | Post |   | 39.48±4.71   | 32.6 | 44.5 |                     |        |
| Push-Up (30 Second)             | Pre  | 8 | 27.63±11.51  | 13   | 45   | 3.75±4.46           | 0.049* |
|                                 | Post |   | 31.38±11.3   | 19   | 48   |                     |        |
| Non-Tabata                      |      |   |              |      |      |                     |        |
| Resting Heart (beat/minutes)    | Pre  | 8 | 101.80±14.44 | 84   | 132  | 16.00±11.95         | 0.007* |
|                                 | Post |   | 85.75±6.71   | 78   | 96   |                     |        |
| Standing Board Jump (cm)        | Pre  | 8 | 153.80±21.09 | 126  | 181  | 11.75±7.28          | 0.003* |
|                                 | Post |   | 165.50±18.76 | 140  | 188  |                     |        |
| Lactate (mg/dL)                 | Pre  | 8 | 10.53±2.06   | 7.8  | 14.8 | 3.26±1.82           | 0.001* |
|                                 | Post |   | 13.79±2.01   | 9.7  | 15.9 |                     |        |
| VO <sub>2</sub> max (ml/kg/min) | Pre  | 8 | 28.81±3.01   | 23.2 | 32.6 | 6.16±4.03           | 0.003* |
|                                 | Post |   | 34.98±5.09   | 27.6 | 42.2 |                     |        |
|                                 | Post |   | 21.13±4.51   | 17   | 28   |                     |        |

\*Mean scores when comparing points from the baseline: a two-tailed sig. < 0.05

using accutrend plus roche has a good level of effectiveness in measuring blood lactate for physical activity (Baldari et al., 2009).

### Statistical analysis

This research uses descriptive tests to present profile sample data. Data Normality Test (Shapiro-wilk) to see the normality of the data. Paired sample t-test was used to see the differences before and after in each group. Two-way ANOVA test with sig. < 0.05 to see the difference in the average of the two groups. Furthermore, the researchers also tested the N-Gain Score to see the Tabata training program's effectiveness for six weeks. To create graphs, all tests were conducted using SPSS version 23 and GraphPad Prisma version 10.

### Results

Table 3 presents data on the results of the normality test using the Shapiro-wilk test, normality data if sig. ≥ 0.05 so that the post Push-up data is declared abnormal.

Table 4 presents the pre and post data on the 5 variables measured in this study. mean and SD data are presented in table 4 to provide an overview of the results of this study. each variable experienced pre and post-test changes through analysis of the Pre-post mean and SD used paired sample t test.

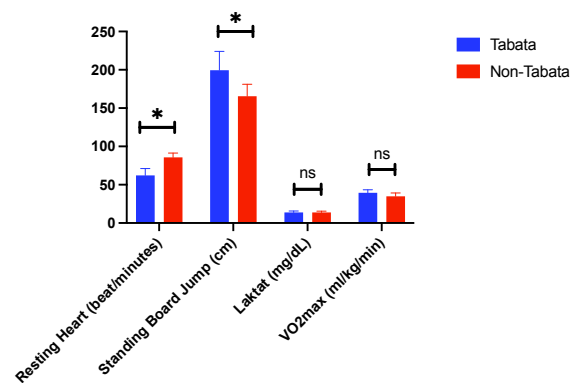


**Fig. 1.** Comparative analysis of six-week average training outcomes for four variables across groups

Fig. 1 shows that only the physiological component (resting heart rate) with the physical component (standing board jump) showed different results after 6 weeks of training between the two groups, where the sig. value of each group sig. < 0.05 (resting heart rate) and (standing board jump). Meanwhile, lactate accumulation and VO<sub>2</sub>max achievement for both groups were the same.

Furthermore, to assess the effectiveness of the training program for 6 weeks of tabata training on resting heart rate

and standing board jump indicators, the N-Gain Score test results showed a value of 88% for resting heart rate and 10% for Standing Board jump. So, it can be concluded that Kempo training using the tabata method is more effective in reducing resting heart rate achievements, on the other hand for SBJ Kempo training using the tabata method is declared ineffective.

## Discussion

This study found that only resting heart rate and standing board jump differed from the control group. The Resting heart rate component is very important to continuously monitor its development because it is directly related to indicators of a person's fitness development (Pramono et al., 2021; Quan et al., 2014). Changes in heart rate are influenced by the type of exercise a person does (Perrone et al., 2021); included in this study were differences in changes in heart rate influenced by exercise using the Tabata method and not using the Tabata method.

Heart performance has been used for a long time as an indicator of the human body's performance. As in research by Garcia (2022), resting heart rate can explain the variance of HR at rest, during exercise testing, and recovery from 11% to 48% (Garcia et al., 2022). Then, the heart rate reserve (HRR) is related to the  $VO_{2max}$  percentage (Matsuura et al., 2019). HRR achievement itself depends on age and resting heart rate. Another effect of Tabata exercise that was not examined in this study and is related to heart rate is decreased blood pressure (Popowczak et al., 2022).

To support a high adolescent lifestyle, a lower RHR value can be used as an indicator and achievement target to support the adolescent lifestyle. As in Samuel's (2022) research, physical activity will support changes in resting heart rate, which will later support adolescent activity patterns (Honório et al., 2022).

Interestingly, in this study, the two groups' physical components (power) were significantly different, but in the N-Gain score assessment, Kempo training using the Tabata method was not considered effective. SBJ is one part of fitness assessment (Brudecki & Gołab, 2006; Yi et al., 2019). The ineffectiveness of Kempo training using the Tabata method is due to the absence of additional indicator elements in training and only using 100% punch and kick techniques as training items for each session. This is in contrast to research (Caglayan & Ozbar, 2017; Gani et al., 2022), which succeeded in increasing power when adding a combination of technical training and functional training.

The next interesting thing in this research is that not all fitness components were successfully obtained through 6 weeks of training using modified Tabata training with Kempo movements. This exercise is only effective in developing resting heart rate because it has an N-Gain Score of 88%. So it's the same as research (Lu et al., 2023) where Tabata training affects cardiorespiratory physiological (Reppa et al., 2023).

Another finding in this study was that Tabata training for 6 weeks involving only Kempo exercise movement techniques increased  $VO_{2max}$  of 8%. This is in line with the results of research by Viana (2019), where variations of training using the Tabata method other than using running and ergo cycle movements will increase by only an average of 11%, while those using running and ergo cycle can increase

by more than 11% (Viana et al., 2019). Even though it is only 8%, this result is quite good if used by someone to increase  $VO_{2max}$  to improve fitness because it uses moderate intensity with interesting movements. High-intensity exercise is not chosen by many teenagers because it causes high levels of stress (Tabata, 2019).

Training using the Tabata method with modified intensity and using Kempo movements for 6 weeks gave significant results in changes in the physiological component (resting heart rate) and the physical component, namely power, even though the power indicator stated that this Tabata training was ineffective. Because of this, this exercise can be applied as part of an exercise program to improve health components in adolescents. Further research needs to be carried out by adding loads and functional training types of exercise to provide a more optimal impact on the aerobic and anaerobic components.

## Conclusions

The research results provide very important findings in the development of physical exercise to improve the health and fitness of adolescents. Kempo training using the Tabata method will provide interesting value in the training patterns that teenagers will carry out. This study found that Tabata training for 6 weeks had an impact on reducing resting heart rate. The development of Kempo training using the Tabata method is considered effective in increasing  $VO_{2max}$ .

Further research development needs to be carried out by future researchers by adding functional training components and providing training loads so that there is an increase in other physical components.

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## Conflict of interest

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

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## ТРАНСФОРМУВАННЯ КЕМПО-ФІТНЕСУ: ПОКРАЩЕННЯ ФІЗІОЛОГІЧНИХ РЕАКЦІЙ І ФІЗИЧНОЇ РЕЗУЛЬТАТИВНОСТІ В ПІДЛІТКІВ ЗА ДОПОМОГОЮ МЕТОДУ НА ОСНОВІ СИСТЕМИ ВПРАВ ТАБАТА

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

Реферат. Стаття: 9 с., 4 табл., 1 рис., 58 джерел.

**Мета дослідження.** Вивчення фізіологічного та фізичного впливу високоінтенсивних інтервальних тренувань за системою Табата з техніками руху кемпо-спорту.

**Матеріали та методи.** Учасниками дослідження були 16 підлітків, яких розподілили на дві окремі групи: група тренувань за системою Табата та група тренувань не за системою Табата. Тренування проводили протягом 6 тижнів, 3 рази на тиждень, кожне заняття тривало 2 години. Тренувальні компоненти для ударів ногами та руками включали Іяку-гері, Дзюн-маваші-гері, Дзюн-цукі та Іяку-маваші-гері. Кожен підліток виконував фізичні вправи один раз на тиждень протягом 2 годин. Для оцінки нормальності даних використовували критерій нормальності (критерій Шапіро-Вілکا). Для вивчення різниці в середніх значеннях між двома групами проводили двофакторний дисперсійний аналіз за рівня значущості менше 0,05. Крім того, для оцінки ефективності 6-тижневої програми тренувань за системою Табата дослідники також тестували показник оцінки нормалізованого приросту. Усі тести проводили з використанням програмного забезпечення SPSS версії 23 та GraphPad Prisma версії 10 для побудовання графіків.

**Результати.** Статистичні дані показують, що 6-тижневе тренування за системою Табата може ефективно знижувати частоту серцевих скорочень у стані спокою та покращувати результативність стрибків у довжину з місця (СДМ) за величини значущості <0,05. У тесті різниці результатів попереднього та підсумкового тестування в рамках групи результати показують значущість <0,05. Результати тестування оцінки нормалізованого приросту показують, що кемпо-тренування за методом на основі системи Табата є ефективними для зниження частоти серцевих скорочень у спокої на величину до 88%, але не є ефективними для збільшення потужності (SBJ) на величину 10%.

**Висновки.** Дослідження показало, що включення методу на основі системи Табата до кемпо-тренувань із необхідними коригуваннями протягом 6 тижнів призвело до помітного зниження частоти серцевих скорочень у стані спокою. Зни-

ження частоти серцевих скорочень у стані спокою є надійним показником покращення рівня фізичної підготовленості та загального самопочуття підлітків.

**Ключові слова:** система Табата, частота серцевих скорочень у стані спокою, модифікація.

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## LEVERAGING EXPERIENTIAL LEARNING TO FOSTER UNIVERSITY STUDENTS' PROFICIENCY IN ENGAGING WITH PEOPLE WITH DISABILITIES

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### Abstract

**Study purpose.** Inclusive education, acknowledged as a fundamental human right, is aimed at enhancing the participation of all students and mitigating social and educational exclusion. Physical Education is identified as a vital instrument that fosters specific training on disability and inclusion, thereby ameliorating attitudes towards disability. The objective of this study is to scrutinize the perception of experiential learning and inclusive physical activity among students.

**Materials and methods.** An inclusive physical activity program for students pursuing a degree in Early Childhood and Primary Education was designed. The program proposes five sessions of inclusive physical activity and accommodates 30 adult users with intellectual disability. To analyse the reliability and validity of a scale that measures students' perception of experiential learning, descriptive statistics, reliability analysis, exploratory and confirmatory factor analysis were used to assess the effectiveness and inclusivity of the scale.

**Results.** The validity and reliability of a scale that facilitates the analysis of students' perceptions of learning derived from inclusive experiences is presented and the results are adequate for its usability. In addition, it is shown that experiential learning increases the perception towards the acquisition of disability-related competences among university students.

**Conclusions.** This scale essentially allows a comprehensive analysis of students' perception of learning that emerges from inclusive experiences. It is demonstrated that experiential learning enhances students' perception regarding the attainment of competencies related to disability. These findings underscore the importance of inclusive learning experiences in the training of future educators.

**Keywords:** inclusion, education, disability, experiential learning, competencies.

### Introduction

Inclusive education is now a top priority in many education systems worldwide and has been acknowledged as a fundamental human right (El Homrani et al., 2019). In higher education, there is growing support for inclusive policies that offer programs catering to all aspects of disability and inclusion (Martínez-Rico et al., 2018). Over time, a shift in perspective has occurred from integration towards inclusive education, which encompasses a wider

vision where all pupils have equal entitlement to receive a quality education under conditions of fairness (Torres & Fernández, 2015). Consequently, inclusion is now regarded as a matter of general education rather than being exclusively related to special education. The concept of inclusion is gaining recognition as a guiding principle for educational policies and practices (Duk et al., 2019). As Perabá (2019) asserts, inclusive education is increasingly vital in our society and has become an essential topic of interest from both an educational and social perspective. Inclusive education aims to boost student participation by decreasing social and academic exclusion (Hernández Fernández & De Barros Camargo, 2021). Additionally, Physical Education (PE) yields a crucial mechanism for fostering inclusion in

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students with SEN (Flores Aguilar, 2019; Stroebel et al., 2019).

### *Conceptual Framework*

Higher education has a duty and responsibility to train future teachers in inclusion as agents of change (Rodríguez García et al., 2023). There is a growing number of initiatives, including lectures, seminars and workshops, aimed at developing inclusive perspectives for future teachers, involving people with and without disabilities (Campos et al., 2021). Exposure to first-hand experiences fosters positive attitudes towards disability, which are later applied in the teaching profession (Abellán et al., 2018; Kwatubana & Bosch, 2019; Nemček, 2022). In this way, a continuous cycle of improving general perceptions of disability is created (Duk et al., 2019). Frequently, the focus shifts from the inclusion of specific populations to the creation of more inclusive educational environments (Hortigüela Alcalá et al., 2022). This is intended to foster an environment where all students feel welcome and valued. This shift in perspective challenges teachers to develop skills that enable them to provide effective and relevant educational responses to the diversity of students, ensuring participation and learning for all.

Inclusive Physical Activity is a practice that aims to promote the participation of all individuals, regardless of their physical abilities, in sport and physical activity (Díaz & Rubinstein, 2021). This initiative supports equity and equal opportunities in physical activity and sport (Muñoz Moreno et al., 2020). In physical activity, inclusion is based on the principle that everyone should have equal opportunities to participate in sport and physical activity, regardless of their physical limitations or abilities. The aim is to remove barriers that may prevent certain individuals from participating, for reasons such as physical or mental disability, age, gender or socio-economic status, among others (Adarve et al., 2019).

Being inclusive in physical activity can provide numerous benefits for participants. An important advantage of this phenomenon is the improvement of public health, which can have potential positive outcomes for both physical and mental well-being, ultimately enhancing overall quality of life. The research of Kuznetsova et al. (2022) suggests that motor play positively affects physical fitness and general well-being, particularly in children with intellectual disabilities. In addition, this activity fosters social cohesion and nurtures social abilities, thus promoting healthy and positive interpersonal connections (Kao, 2019).

To achieve the goals of inclusive education, teachers hold a vital position. However, PE teachers often face a deficiency in confidence and preparation required to effectively execute this practice (Hutzler et al., 2019). As a result, numerous teachers find it unfeasible to achieve inclusion due to the perceived lack of competency and inadequate resources (Valencia-Peris et al., 2020). Studies, such as Reina et al. (2021), have examined the impact of a disability awareness programme that was implemented in genuine educational environments. In their schools, physical educators developed and put into practice interventions aimed at raising disability awareness. Physical education teachers were able to influence the attitudes of their students towards inclusion through awareness-raising activities. The effectiveness of

these interventions was considered by taking into account the ecology of the setting and the baseline attitudes of the students prior to the sessions.

In recent years, the notion of the relationship between knowledge acquisition and educational innovation has expanded. For example, Martínez-Rico et al. (2018) suggest thorough policies on a worldwide scale to integrate disability care and inclusion schemes in universities' educational strategies. Initially, innovations in education were predominantly viewed as results of R&D expenditures and the circulation of research-based understanding. In current times, innovations are considered part of the process of learning and knowledge creation, specifically within academic institutions (Gaglio et al., 2022). The effectiveness of various innovative educational approaches is perceived to improve essential skills required for students' employability, such as teamwork, communication, creativity, organisation, and information management. However, the use of such methodologies may not lead to significant modifications of some of these competencies (Parrado-Martínez & Sánchez-Andújar, 2020).

The study conducted by Reina et al. (2022) analyses the impact of an awareness intervention programme on the attitudes of PE students towards the inclusion of their classmates with disabilities. The groups that had contact with para-athletes during the programme reported marked improvements in the attitudes of students with disabilities. The study highlights the efficacy of this intervention programme in promoting inclusive attitudes amongst PE students.

The implementation of didactic methodologies emphasising practical content can significantly influence learning outcomes. In contrast to traditional teaching methods, this approach has a moderately advantageous impact on students' academic achievement, cognitive competence, and emotional dispositions, as found by Zhang and Ma (2023).

Experiential learning is acknowledged as a significant pedagogical instrument that enhances learning outcomes (Coker et al., 2017; Hajshirmohammadi, 2017; Morris, 2016). These methods have been used for more than 40 years to improve student learning. Nonetheless, limited research has been conducted to investigate the effectiveness of such strategies (Burch et al., 2019). Experiential Learning Theory (Kolb, 2014) suggests that a concrete encounter encourages students to reflect and contemplate on the experience until they can develop abstract conceptualizations that link the experience to previous ones, ultimately resulting in responsive experimentation when deciding how to apply the experience in future actions. Experiential learning is thought to improve students' learning at a higher order level, which includes the development of critical thinking skills and the ability to be self-directed learners (Kreber, 2001). Experiential learning refers to actively processing an experience, which results in acquiring new knowledge, skills, attitudes, and perceptions (Burch et al., 2019).

The efficacy of hands-on experience on enhancing student learning has been scrutinised in a multitude of studies. Ilyas et al. (2020) contend that experiential learning imbues students in higher education with proficiencies that ameliorate their learning processes. Additionally, Thomsen et al. (2021) purport that when paired with introspection

and classroom debate, experiential learning engenders students' greater maturation. Thus, active learning is an essential aspect of understanding the teaching and learning process. This approach focuses on applying knowledge to a student's own experiences (Parrado-Martínez & Sánchez-Andújar, 2020).

Research by Zhang and Ma (2023) suggests that experiential learning enhances academic performance while also impacting students' self-emotional attitudes, values, and higher-order thinking skills. To ensure inclusivity in a university environment, proactive measures must be taken to eliminate barriers that impede learning and full participation of students. The social model of disability emphasizes this need (López Gavira & Moríña, 2015), and the University must commit to implementing such measures. Inclusive higher education is based on a comprehensive set of principles that go beyond simply identifying obstacles and finding solutions. Kioko and Makoelle (2014) consider various factors in creating an inclusive learning environment in universities. This necessitates modifying professional practices and conditions, actively removing barriers, offering reasonable accommodations to students, and utilizing technology to facilitate learning access. To promote inclusivity in educational institutions, it is crucial to proactively improve learning settings to protect student diversity and foster social involvement among all students (Vetoniemi & Kärnä, 2021). Research, including Lübke et al. (2021) study, emphasises the significance of flexible learning environments in promoting inclusive education. The study demonstrated that these settings had a direct impact on the attitudes towards pupils, regardless of disabilities, social welfare benefits for pupils with emotional and behavioural problems, and self-efficacy for promoting social abilities. Furthermore, adaptable learning settings had indirect consequences on intentions and conduct.

In conclusion, inclusive education offers a potentially fertile and advantageous environment for students to learn, develop, relate, and create a collective culture promoting inclusion (Agran et al., 2017). Hence, the main aim of this study is to analyze the perceptions of students, future teachers, regarding their experiential learning through the practice of inclusive physical activity.

## Materials and methods

### Study participants

The participants in this work are a total of 60 students who are studying for a degree in Early Childhood and Primary Education. Twenty percent of the participants were women compared to 80% men. The mean age of the participants was 22.59 years ( $dt = 2.59$ ), with a minimum age of 20 years and a maximum age of 31 years. Of these, 33% indicated that they had some kind of contact with people with functional diversity compared to 67% who indicated that they had no previous contact with people with functional diversity.

### Research organization

To conduct the research, the program design proposes five sessions of inclusive physical activity. The content of each session is pre-established in the relevant subject's teaching

guide. The sessions were designed based on: 1) The course covered the development and evaluation of capabilities, motor skills, and physical expression, as well as 2) individual and team sports, 3) the biological and physiological foundations of movement and physical abilities, and 4) the management of physical activity, health, and specialized educational requirements. Additionally, it explored the planning of physical education (PE) through theoretical and practical didactics. The sessions were two hours long and comprised of warm-up exercises, a main segment, and a cool-down period. At the end of each session, there is a 15-minute slot allocated for reflection. During this time, students present their experience of the resources, contents and training provided in the session using a script designed by the teachers. The program accommodates 30 adult users with intellectual disability who are part of the Asindown Foundation (Valencia) and enrolled in the Capacitas-Asindown employment training program.

### Research methods

The students who took part in the study completed the questionnaire a week before the commencement of the project and again two weeks after its conclusion. The questionnaire comprised a 6-item Likert scale adapted from Byrne & Flood's (2003) generic skills scale, where participants indicated their level of agreement on a 1-5 scale, with 1 representing strong disagreement and 5 representing strong agreement. In order to conduct this research, approval was granted by the Research Ethics Committee of the Catholic University of Valencia (Project Code UCV/2021-2022/213). Participants will receive a written informed consent form detailing project data, the information collection process, the implications of their participation, their rights, the option to withdraw from the study at any time, the methods for data collection and use during the research, as well as the dissemination and transfer of information.

### Statistical analysis

The statistical package JASP v. 0.16 (JASP Team, 2022) was used for descriptive statistics, reliability analysis, exploratory factor analysis (EFA), and confirmatory factor analysis (CFA). The validity and reliability of the scale, in a first approach, the factor structure was studied through the AFE to identify the latent structure of the variable as a process of theory generation, and AFC as a theoretical testing procedure of the results suggested by the EFA (Pituch & Stevens, 2015) the authoritative textbook Applied Multivariate Statistics for the Social Sciences, continues to provide advanced students with a practical and conceptual understanding of statistical procedures through examples and data-sets from actual research studies. With the added expertise of co-author Keenan Pituch (University of Texas-Austin, AFC allows us to specify the number of factors and items to be tested. In addition, we used R (R core team, 2022) to calculate the ordinal alpha and McDonald's Omega, with values above 0.8 and 0.7 respectively, indicating good internal consistency of the scores.

Hypotheses for factor analysis were examined, such as: item ratio, sample size, normality, linearity and correlation between variables (Tabachnick & Fidell, 2019). Assuming

an oblique relationship between variables, the Promax rotation method was used to perform the AFE. To explore the underlying factors, we used eigenvalue greater than 1 (Harman, 1976) with the weighted least squares (WLS) extraction method due to the ordinal nature of the data. Internal consistency was analyzed through Cronbach's alpha, ordinal alpha, and McDonald's omega values. We also calculated the adequacy of the data through the homogeneity test, the KMO index and Bartlett's test of sphericity (Kaiser, 1974). Through AFC, however, we test the data fit to the solution given by the EFA. We employed diagonally weighted least squares estimation for CFA. The corresponding indices were Chi-square, the comparative fitness index (CFI) and goodness-of-fit index (GFI). A non-significant chi-square test indicates an adequate fit to the data. A CFI and GFI close to 1.0 indicate an excellent fit to the data (Hu & Bentler, 1999). Finally, a paired samples t-test was performed to determine the sensitivity of the scale to capture changes in student perceptions. For this purpose, the Wilcoxon signed-rank test was calculated to compare the mean rank of two related samples and determine if there are differences between them. In turn, the effect size of this difference was calculated.

## Results

In terms of results, to assess normality, skewness and kurtosis values were examined and found to be below the criterion of 3.0 recommended by Hu & Bentler (1999). The skewness and kurtosis values for all scale items, except item 3, were lower than 3.0. Table 1 displays descriptive statistics.

Next, an EFA was performed on the experiential learning scale. The Kaiser-Meyer-Olkin was 0.75 and Bartlett's test of sphericity was statistically significant:  $\chi^2 = 82.968$ ,  $df = 23$ ,  $p < .001$ . The  $\chi^2/df$  index analysis equals 3.6, lower than the literature recommended cutoff point of ( $< 5$ ) (Schumacker &

Lomax, 2004)2004. These results suggested the adequacy of the data for factor analysis.

Promax rotation and weighted least squares (WLS) estimation were used for the exploratory factor analysis. The solution extracted a factor with the 5 items with factor loadings above 0.71 and explained 52.20% of the variance.

**Table 2.** Measures of fit of the scale of experiential learning perceived by the students

|                    | Factor Loadings | Mean (sd)      | Item-element correlation | Unicity |
|--------------------|-----------------|----------------|--------------------------|---------|
| Item 1             | 0.89            | 4.41<br>(0.64) | 0.78                     | 0.20    |
| Item 2             | 0.81            | 4.44<br>(0.63) | 0.71                     | 0.34    |
| Item 3             | 0.71            | 4.52<br>(0.74) | 0.76                     | 0.49    |
| Item 4             |                 |                |                          |         |
| Item 5             | 0.72            | 4.44<br>(0.64) | 0.64                     | 0.49    |
| Item 6             | 0.73            | 4.30<br>(0.68) | 0.69                     | 0.46    |
| $\alpha$           |                 |                | 0.82                     |         |
| $\omega$           |                 |                | 0.74                     |         |
| Ordinal Alpha      |                 |                | 0.87                     |         |
| Eigenvalue         |                 |                | 3.53                     |         |
| AVE                |                 |                | 0.50                     |         |
| Explained Variance |                 |                | 0.52                     |         |

Note. The rotation method applied is varimax.  $\alpha$  = Cronbach's alpha;  $\omega$  = McDonald's Omega; AVE = Average variance extracted.

**Table 1.** Mean, standard deviations, skewness, and kurtosis of student-perceived experiential learning

| No    | Content                                                                                                                                                                                                                                                                                          | M    | SD   | skewness | Kurtosis |
|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|----------|----------|
| 1     | El aprendizaje experiencial desarrolla mis habilidades para interactuar con personas con discapacidad. "Experiential learning develops my skills in interacting with people with disabilities."                                                                                                  | 4.41 | 0.64 | -0.72    | -0.34    |
| 2     | El aprendizaje experiencial perfecciona mis habilidades para trabajar con personas con discapacidad. "Experiential learning hones my skills in working with people with disabilities."                                                                                                           | 4.44 | 0.63 | -0.67    | -0.76    |
| 3     | El aprendizaje experiencial me ayuda a desarrollar mi capacidad de relacionarme con personas con discapacidad. "Experiential learning helps me develop my ability to relate to people with disabilities."                                                                                        | 4.52 | 0.74 | -1.99    | 4.33     |
| 4     | Como resultado del aprendizaje experiencial me siento seguro al interactuar con personas con discapacidad. "As a result of experiential learning I feel confident interacting with people with disabilities."                                                                                    | 4.41 | 0.57 | -0.27    | -1.44    |
| 5     | El aprendizaje experiencial mejora mis habilidades a la hora de interactuar con personas con discapacidad. "Experiential learning enhances my skills in interacting with people with disabilities."                                                                                              | 4.44 | 0.64 | -0.96    | -0.03    |
| 6     | El aprendizaje experiencial me ayuda a desarrollar la capacidad de utilizar recursos para potenciar mi formación en relación con el ámbito de la discapacidad. "Experiential learning helps me develop the ability to use resources to enhance my training in relation to the disability field." | 4.30 | 0.68 | -0.55    | -0.75    |
| Total |                                                                                                                                                                                                                                                                                                  | 4.42 | 0.50 | -0.80    | -0.09    |

**Table 3.** Mean, standard deviations, skewness and kurtosis of experiential learning perceived by students pre- and post-intervention

|        | PRE  |      |       |       | POST |      |       |       |
|--------|------|------|-------|-------|------|------|-------|-------|
|        | Mean | SD   | S     | K     | Mean | SD   | S     | K     |
| item 1 | 4.22 | 0.8  | -0.43 | -1.28 | 4.81 | 0.4  | -1.77 | 1.28  |
| item 2 | 4.33 | 0.73 | -0.63 | -0.81 | 4.69 | 0.6  | -1.89 | 3.03  |
| item 3 | 4.41 | 0.84 | -1.34 | 1.16  | 4.81 | 0.54 | -3.03 | 9.09  |
| item 5 | 4.3  | 0.72 | -0.52 | -0.85 | 4.81 | 0.54 | -3.03 | 9.09  |
| item 6 | 4.19 | 0.87 | -0.75 | -0.29 | 4.5  | 0.63 | -0.79 | -0.23 |

Note. SD = standard deviation; S = skewness; K = kurtosis

Table 3 presents the factor loadings for the AFE, showing the suggested one-factor solution. Internal consistency of scores with this subsample ( $n = 60$ ) indicated Cronbach's alpha ( $\alpha = 0.82$ ), McDonald's omega ( $\omega = 0.74$ ) and ordinal alpha (0.87). There were no improvements in the internal consistency of the scores. No improvements in Cronbach's alpha or McDonald's alpha were found if items were removed.

Thus, the results of the EFA analysis showed factor weights between 0.71 and 0.89 and all the estimates were statistically significant, except for item 4, which was eliminated from the analysis due to inconsistency in the factor loadings, which were less than 0.40. These data can be seen in Table 2.

The results of this factor analysis showed a good fit of the factor structure. The value of the comparative fit index (CFI = 0.90) and goodness-of-fit index (GFI = 0.93) were higher than the recommended cut-off point ( $> 0.90$ ). The eigenvalue (3.53) and average variance extracted (AVE = 0.50) indices were also calculated, the latter being higher than the cut-off point recommended by the literature (Baggozi et al., 1998).

Next, a comparative analysis was performed between the entire sample ( $n = 60$ ) pre-intervention and post-intervention to evaluate the degree of implementation of the construct analyzed in the student. The descriptive results of the analysis for related samples show us an increase in the score in all the items of the scale. This can be observed in Table 3.

**Table 4.** Mean, standard deviations, Wilcoxon signed rank and effect size of experiential learning perceived by students pre and post intervention

|                          | PRE  |      | POST |      | w     | p     | Effect Size |
|--------------------------|------|------|------|------|-------|-------|-------------|
|                          | M    | SD   | M    | SD   |       |       |             |
| Aprendizaje experiencial | 4.21 | 0.61 | 4.69 | 0.40 | -2.76 | 0.007 | -0.94       |

Note. M = Mean; SD = standard deviation

The results of the related samples analysis showed that students who participated in the educational innovation project obtained significantly higher scores ( $w = -2.67$ ,  $p < 0.001$ ) after the intervention ( $M = 4.69$ ,  $SD = 0.40$ ) than before the intervention ( $M = 4.21$ ,  $SD = 0.61$ ), indicating that the scale was sensitive enough to capture differences in pre-intervention and post-intervention scores.

## Discussion

Specific training in disability and inclusion is essential to promote genuine inclusion and improve attitudes towards disability (Haegele et al., 2018). However, it is equally important to implement and practice inclusive activities. As demonstrated by the results of the research, working towards inclusion promotes and enhances beliefs about disability, personal value, and attitudes towards peers (González & Cortés, 2016). To Díaz & Rubinstein (2021), inclusive physical activity is a practice that strives to foster the engagement of individuals from diverse backgrounds, regardless of their abilities. It is underpinned by the principles of equity and equal opportunities within the sphere of sports and physical activities (Muñoz Moreno et al., 2020). The core philosophy propelling the promotion of inclusion in physical activity is the belief that participation in sports and physical activities is a right that should be accessible to all, irrespective of any limitations or abilities (Kiuppis, 2018). This practice is dedicated to eliminating barriers that might obstruct the participation of individuals with disabilities, thereby ensuring a more inclusive environment.

Campos et al. (2021) suggest that higher education provides optimal circumstances for experiential and reflective learning by promoting inclusive physical activity that involves both disabled and non-disabled students in the same training environment. The study findings emphasize the significance of experiential learning in enhancing university students' attitudes towards disability. Following the implementation of inclusive physical activity sessions, in our research, students demonstrated a significant improvement in their perception of learning related to disability. These findings endorse the notion that inclusive education, especially inclusive physical activity, can effectively changing attitudes and perceptions towards disability have an impact on other variables, as noted in studies such as that of Nemček (2022). Additionally, the outcomes emphasize the fundamental role of educators in endorsing and executing all-inclusive knowledge. Nevertheless, numerous teachers may experience uncertainty or a lack of preparation to carry out this assimilation effectively (Hutzler et al., 2019). This investigation's findings propose that, with appropriate tools and resources, it is possible to attain a substantial shift in pupils' perspectives and beliefs towards disabilities. The findings demonstrate that experiential learning and inclusive physical activity have a significant impact on improving perceptions of disability among students. Nonetheless, it

is vital to equip teachers with the adequate competencies, skills, and resources to effectively implement these practices (Valencia-Peris et al., 2020). With the appropriate support, teachers play a crucial role in promoting more comprehensive and equitable education.

Several studies have demonstrated the necessity of examining experiential learning (Burch et al., 2019) for its potential to enhance learning outcomes positively. However, disability is an area that requires additional investigation. Overall, experiential learning has numerous benefits, including better retention and transfer of knowledge, heightened motivation and engagement, and the acquisition of practical skills and competencies (Liu & Pásztor, 2022). The findings of this study indicate that incorporating meaningful experiences in educational settings can significantly improve the acquisition of competencies within the field of functional diversity. It is noteworthy, however, that the advantages of experiential learning are context-, learner-, and experience-dependent (Liu & Pásztor, 2022).

The study findings should be interpreted with care and applied only to the relevant population. Nonetheless, they offer a trustworthy and dependable mechanism to evaluate the degree of proficiency achieved through experiential learning in relation to the realm of functional diversity among students.

This study has limitations that could impact the findings. The sample population is insufficient to produce conclusive results, despite being based on the participation in an organized educational innovation proposal with all students included in the study. In future research, extending the intervention by increasing session numbers would be worthwhile. Furthermore, it would be expedient to utilize this validated tool in various contexts and practical applications. Additionally, the tool could be customized for other contexts that are relevant to the field of inclusion and applied to all individuals who come into contact with functional diversity.

## Conclusions

In conclusion, the study highlights the effectiveness of inclusive physical activity in altering attitudes and perceptions towards functional diversity, particularly intellectual disability. Moreover, the significance of experiential learning in enhancing perspectives towards disability among university students is emphasized. After implementing inclusive physical activity sessions, students' perception of learning about disability significantly improved. Specific training on disability and inclusion is crucial for improving attitudes towards disability and promoting genuine inclusion in educational and social settings. However, the implementation and practice of inclusion-related activities are equally important, as they contribute to inclusion and improve beliefs and attitudes towards disability. The education sector plays a pivotal role in promoting and implementing inclusive education for the entire society.

Although some professionals may lack confidence or preparation to effectively implement inclusion practices, the study's findings suggest that appropriate tools and resources can bring about a notable shift in students' attitudes and perceptions towards functional diversity.

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## Conflict of interest

There is not any conflict of interest.

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## МАКСИМАЛЬНО ЕФЕКТИВНЕ ВИКОРИСТАННЯ ЕМПІРИЧНОГО НАВЧАННЯ ДЛЯ СПРИЯННЯ РОЗВИТКУ МАЙСТЕРНОСТІ СТУДЕНТІВ УНІВЕРСИТЕТІВ У РОБОТІ З ЛЮДЬМИ З ОБМЕЖЕНИМИ МОЖЛИВОСТЯМИ

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

Реферат. Стаття: 9 с., 4 табл., 51 джерело.

**Мета дослідження.** Інклюзивна освіта, визнана фундаментальним правом людини, спрямована на розширення участі всіх студентів та обмеження соціальної та освітньої ізоляції. Фізичне виховання визначають як життєво важливий інструмент, який сприяє розвитку спеціального навчання з питань інвалідності та інклюзії, тим самим покращуючи ставлення до інвалідності. Метою цього дослідження є уважне вивчення сприйняття студентами емпіричного навчання та інклюзивної фізичної активності.

**Матеріали та методи.** Розроблено програму інклюзивної фізичної активності для студентів, які навчаються за спеціальністю «Дошкільне виховання та початкова освіта». Ця програма передбачає п'ять занять з інклюзивної фізичної активності та розрахована на 30 дорослих користувачів із порушенням інтелектуального розвитку. Щоб проаналізувати надійність і валідність шкали, яка вимірює сприйняття студентами емпіричного навчання, використовували описову статистику, аналіз надійності, експлораторний і конфірмаційний факторний аналіз для оцінки ефективності та інклюзивності шкали.

**Результати.** Представлено валідність і надійність шкали, яка полегшує аналіз сприйняття студентами навчання, отриманого на основі інклюзивного досвіду, і ці результати є достатніми для її придатності до використання. Крім того, показано, що емпіричне навчання покращує ставлення студентів університетів до набуття пов'язаних з інвалідністю компетенцій.

**Висновки.** Ця шкала, по суті, дозволяє комплексно проаналізувати сприйняття студентами навчання, яке впливає з інклюзивного досвіду. Показано, що емпіричне навчання покращує уявлення студентів щодо набуття пов'язаних з ін-

валідністю компетенцій. Ці одержані результати підкреслюють важливість досвіду інклюзивного навчання у підготовці майбутніх освітян.

**Ключові слова:** інклюзія, освіта, інвалідність, емпіричне навчання, компетенції.

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ORIGINAL SCIENTIFIC ARTICLE

## EFFECTS OF CONTRAST TRAINING WITH TWO SESSIONS WEEKLY FREQUENCY ON PHYSICAL FITNESS OF UNIVERSITY-LEVEL MALE SOCCER PLAYERS

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### Abstract

**The purpose of this study** was to compare the effects of a six-week contrast training intervention conducted twice per week during the preparatory period on the measures of physical fitness in university-level male soccer players.

**Materials and methods.** Sixteen players were selected as participants and randomly assigned to an experimental group or an active control group. Data were collected at baseline and after a six-week training intervention period for 15 m and 30 m linear sprint, medicine ball throw (MBT), standing long jump (SLJ), countermovement jump (CMJ), change of direction speed (CODS), peak torque (both legs) during extension and flexion, and running-based anaerobic sprint test (RAST).

**Results.** The analysis revealed reported significant small to very-large magnitude within-group improvement in all the dependent variables for the experimental group ( $p < 0.001$ - $0.028$ ) but not for the control group ( $p = 0.066$ - $1.000$ ). Further, the analysis of covariance with the pre-test scores as covariates revealed significant differences at post-intervention assessments for all the dependent variables, favoring the contrast training group ( $p < 0.001$ - $0.05$ ).

**Conclusions.** A six-week contrast training intervention with two weekly sessions during the preparatory period may be sufficient to induce small improvement in the 30 m linear sprint and isokinetic strength of both legs, moderate improvement in the 15 m linear sprint, and MBT, large improvements in SLJ, RAST, and a very large improvement in vertical jump (CMJ) and CODS.

**Keywords:** football, muscle strength, resistance training, plyometric exercise, human physical conditioning, athletic performance.

### Introduction

Soccer is an intermittent sport that requires players to execute different actions demanding explosiveness of the lower limb (Stølen et al., 2005). These explosive actions may range from short sprints to win the ball possession up to kicking to score a goal. Most essential actions in soccer are time-bound and require quick application of force (i.e., high rate of force development) (Taber et al., 2016). Therefore, players need the ability to exert maximal force in a minimal time. Hence, it becomes crucial for soccer players to improve these abilities. Moreover, strength (i.e., the ability to exert maximal force), as well as power (i.e., the ability to exert

maximal force in minimal duration), has been reported to be associated with different physical fitness abilities among soccer players (Arnason et al., 2004; McFarland et al., 2016; Thapa et al., 2019; Wisløff et al., 2004), which are crucial for a soccer game. For example, strength and power are associated with linear sprint, one of the most common soccer actions before scoring a goal (Faude et al., 2012). Indeed, previous studies have reported that strength, aerobic endurance, and other physical fitness abilities can also help discriminate elite players from amateur players (Bangsbo et al., 2008; Cometti et al., 2001). Therefore, training methods to improve these abilities become paramount for soccer players' success.

Different strength training methods are available to improve soccer players' physical fitness. However, traditional resistance training and plyometric training are two commonly used methods. Traditional resistance

training encompasses using external loads (commonly heavier loads). In contrast, plyometric training utilizes the individuals' body mass (sometimes plyometric training may utilize external resistance too [e.g., resistance bands]) (Barrio et al., 2023; Ojeda-Aravena et al., 2023; Ramirez-Campillo et al., 2022; Ramirez-Campillo et al., 2023; Rath et al., 2023). These distinct differences in the load allow both exercises to be performed with different forces and velocities, putting both at almost opposite ends of the force-velocity spectrum (Kumar, Pandey, Thapa, et al., 2023; Thapa & Kumar, 2023; Thapa et al., 2021; Thapa et al., 2022). Therefore, including only one training method may reduce the overall force-velocity development of a given athlete. Hence, including traditional resistance and plyometric training within a training periodization of soccer players becomes essential.

However, including both training methods on separate days (i.e., compound training) within a congested weekly micro-cycle is often difficult. For example, a coach working with an amateur university-level soccer team may be able to conduct only one session per day, i.e., five training sessions per week. In such a scenario, it becomes difficult to include both traditional resistance training and plyometric training on separate days. A pragmatic approach is to have both traditional resistance training and plyometric training within a single session. Such a training approach is termed complex training (Thapa et al., 2021). Amongst the different possible combinations of both training methods (four combinations are available), complex-contrast training (CT) is done by performing the traditional resistance exercise first, followed by plyometric exercise, in a set-by-set fashion (Kumar, Pandey, Thapa, et al., 2023; Thapa & Kumar, 2023; Thapa et al., 2022). It is suggested that with such a combination, the heavier load performed in the form of traditional resistance exercise activates a larger motor unit pool, thereby enhancing the lower load exercise performance (i.e., plyometric training exercise) (Thapa & Kumar, 2023; Thapa et al., 2021; Thapa et al., 2022).

Moreover, using both traditional resistance exercise and plyometric exercise in such a format may save time while also inducing improvements. Indeed, previous meta-analyses have reported that CT improves sprint, change of direction speed (CODS), and jumps (Thapa et al., 2021) while also enhancing the maximal strength (Thapa et al., 2022) of soccer players. In addition, both meta-analyses (Thapa et al., 2021; Thapa et al., 2022) reported a need for more studies during the pre-season period. According to the authors, only three studies conducted CT during pre-season (Kumar, Pandey, Ramirez-Campillo, et al., 2023; Maio Alves et al., 2010a; Miranda et al., 2022). Furthermore, replication of sports and exercise science studies is needed to increase the rigor of science and advancement of knowledge (Murphy et al., 2023). Therefore, this study aimed to compare the effects of a CT intervention during the preparatory period on soccer players' physical fitness abilities. Based on previous evidence, it was hypothesized that significant improvement would be observed in all the physical fitness abilities after the CT intervention compared to the active control group.

## Methods

### Participants

Sixteen male amateur soccer players who participated in the University-level competitions were recruited as

participants for this study. A priori sample size estimation suggested this sample size be sufficient to detect a large effect (Cohen  $f = 0.4$ ) within-between interaction in repeated measures design with a power of 0.80. Participants were required to practice regularly (minimum five hours per week) during the preparatory training camp for the inter-university competitions and have a minimum of one year of resistance training experience to be eligible for the study. In addition, participants were excluded if they had any lower-limb injury in the past six months before the start of the study. After that, the participants were allocated randomly to either the experimental training group ( $n = 8$ ) that practiced regular soccer training combined with CT or an active control group ( $n = 8$ ) that practiced soccer training alone. The demographic characteristics of the participants are presented in Table 1. The participants signed informed consent forms after being explained the potential risks and benefits of the study. The study was approved by the University's Internal Review Board and conducted following the declaration of Helsinki.

**Table 1.** Participant demographics of complex-contrast training (CT) and active control group (CG)

|                | CT ( $n = 8$ )  | CG ( $n = 8$ )  | p-value*           |
|----------------|-----------------|-----------------|--------------------|
| Age (yrs)      | 20.3 $\pm$ 1.8  | 21.4 $\pm$ 1.2  | 0.233 <sup>a</sup> |
| Height (cm)    | 171.4 $\pm$ 6.7 | 174.6 $\pm$ 5.0 | 0.296              |
| Body Mass (kg) | 61.7 $\pm$ 4.0  | 68.7 $\pm$ 6.3  | 0.018              |

Note: \* – independent t-tests, <sup>a</sup> – Mann Whitney U Test (non-normal data)

### Procedure

Familiarization sessions were conducted for the testing protocols and CT exercises before the start of the study. One repetition-maximum (1RM) assessment for the experimental group (i.e., for training prescription) was done during this period. In addition, demographic data were also collected during the same period. Participants were asked to avoid strenuous activity for 48 hours and eat habitually before the testing day. Two (within-subject, pre- and post-) by two (between subject; experimental and control) randomized controlled design was used to compare the training effects on selected outcome variables. The tests were conducted at identical times during pre- and post-intervention assessments, with the sequence of testing order remaining the same for all the participants. A ten-minute general warm-up procedure was conducted before the testing, with some specific trials before each assessment.

### Load measurement and Training intervention

The prescription of load for the experimental group was based on the percentage of 1RM assessed before the start of the study. Furthermore, the contrast pairs of exercises were selected based on previous studies (Kumar, Pandey, Ramirez-Campillo, et al., 2023; Kumar, Pandey, Thapa, et al., 2023; Thapa & Kumar, 2023). Squats were paired with squat jumps, deadlifts were paired with kettlebell swings, barbell lunges were paired with barbell high knees, and bench presses were paired with plyometric push-ups. The

load at the initial two weeks was 65% 1RM for the high-load exercise, followed by 75%1RM for the next two weeks and 85%1RM for the final two weeks. The training sessions' load description is presented in Table 2.

**Table 2.** Description of training load across a six-week duration

|          | High-load exercise | Low-load exercise   |
|----------|--------------------|---------------------|
|          | Set × repetitions  |                     |
| Week 1-2 | 3 × 15             | 3 × 6/10/15 sec/6*  |
| Week 3-4 | 3 × 10             | 3 × 8/10/20 sec/8   |
| Week 5-6 | 3 × 6              | 3 × 10/10/25 sec/10 |

Note: \*repetitions are represented as squat jumps/kettlebell swings/barbell high knees/plyometric push-ups

### Outcome variables

Linear sprint tests included 15 m and 30 m distances conducted separately to measure acceleration speed and maximal speed on synthetic outdoor track based on protocols used in previous studies (G. Singh et al., 2022; Gaurav Singh et al., 2022). Similarly, the change of direction speed test was conducted on an outdoor natural grass field (participants wore their soccer boots) based on protocols described in previous studies (R. K. Thapa, F. M. Clemente, et al., 2023; Rohit K Thapa et al., 2023). For both the timing-based tests, two experienced timekeepers were recruited who recorded three trials of each test, with a rest period of ~3 minutes between trials. Upper body explosive strength was assessed using a backward medicine ball throw based on methods described in a previous study (Stockbrugger & Haennel, 2001). The vertical jump was evaluated using the countermovement jump test with a valid and reliable inertial measurement unit (S. Kumar et al., 2023), while the standing long jump (SLJ) test was used to assess the horizontal jumps (Gaurav Singh et al., 2022). The peak torque during flexion and extension of both legs was measured using an isokinetic dynamometer (Humac NORM). While the maximal anaerobic power was estimated using a running-based anaerobic sprint test (Zagatto et al., 2009). For all the assessments (except the running-based anaerobic sprint test), three successful trials were conducted with a minimum of ~3 minutes rest between each trial. The interclass correlation coefficient with its 95% confidence interval is presented in Table 3.

### Statistical Analysis

The analyses were conducted using SPSS version 24.0.0 (IBM, New York, USA). Data are presented as means and standard deviations. The normal distribution of the data and its homogeneity of variance were verified using the Shapiro-Wilk and Levene's tests for equality of variances, respectively. After that, analysis of covariance (ANCOVA) with baseline scores as a covariate was used to analyze the training-specific effects. Post hoc pairwise comparisons were conducted for significant differences to find which group was favored. Within-group changes were analyzed using a paired t-test. Percentage change scores were also calculated for the dependent variable in each group using the equation in a customized Microsoft Excel sheet:

**Table 3.** Interclass correlation coefficient (ICC) and their 95% confidence interval (CI)

| Variables                        | ICC  | 95 % CI     |
|----------------------------------|------|-------------|
| 15 m sprint (s)                  | 0.87 | 0.68 – 0.95 |
| 30 m sprint (s)                  | 0.78 | 0.50 – 0.91 |
| Medicine Ball Overhead Throw (m) | 0.95 | 0.86 – 0.98 |
| Standing Long Jump (m)           | 0.84 | 0.62 – 0.94 |
| CMJ height (cm)                  | 0.93 | 0.82 – 0.97 |
| Modified Agility T-test (s)      | 0.80 | 0.54 – 0.92 |
| PT leg extension (right) (Nm)    | 0.98 | 0.96 – 0.99 |
| PT leg flexion (right) (Nm)      | 0.95 | 0.88 – 0.98 |
| PT leg extension (left) (Nm)     | 0.98 | 0.96 – 0.99 |
| PT leg flexion (left) (Nm)       | 0.95 | 0.88 – 0.98 |

$[(\text{meanpost} - \text{meanpre}) / \text{meanpre}] \times 100$ . Effects sizes (ES) in the form of partial eta squared ( $\eta_p^2$ ) were used from ANCOVA output. Hedge's  $g$  were calculated to assess the ES between pre-post measurements testing for each group. The magnitude of effects for  $\eta_p^2$  was interpreted as small ( $<0.06$ ), moderate ( $\geq 0.06 - 0.13$ ), and large ( $\geq 0.14$ ) (Cohen, 1988), while Hedge's  $g$  was interpreted as trivial ( $<0.2$ ), small ( $0.2 - 0.6$ ), moderate ( $>0.6 - 1.2$ ), large ( $>1.2 - 2.0$ ), and very large ( $>2.0 - 4.0$ ) (Hopkins et al., 2009). The interclass-correlation coefficient between trials was interpreted as poor ( $<0.5$ ), moderate ( $0.5 - 0.75$ ), good ( $0.75 - 0.9$ ), and excellent ( $>0.9$ ) reliability based on the lower bound of the 95% confidence interval (Koo & Li, 2016). Statistical significance was set at  $p \leq 0.05$ .

## Results

### Main outcomes

Table 4 provides comprehensive detail regarding the analysis of the data. The Shapiro-Wilk test results ( $p > 0.05$ ) indicated that all variables were normally distributed. A positive training adaptation was found for the CT group for all the selected dependent variables. The within-group magnitude of improvement after CT intervention across all the variables ranged from small to very large. A substantial improvement (large or very large ES) ( $g > 1.20$ ) was observed in variables such as SLJ ( $g = 1.424$ ,  $p = 0.001$ ), CMJ ( $g = 6.660$ ,  $p < 0.001$ ), CODS ( $g = 2.786$ ,  $p = 0.001$ ), and average power ( $g = 1.422$ ,  $p < 0.001$ ). In the control group, no notable changes were detected for any dependent variables from pre to post-intervention assessments. Further, the percentage change from pre- to post-intervention for both the groups is presented in Figure 1.

The ANCOVA (Table 4) results displayed significant differences in all the selected outcome variables at the post-test after the six-week intervention, favouring the CT group. The ES ( $\eta_p^2$ ) derived from the ANCOVA output suggests the magnitude of differences was large ( $>0.14$ ).

## Discussion

The study aimed to find the effects of six-week CT with a weekly frequency of two sessions during the preparatory period on measures of physical fitness among university-

**Table 4.** Statistical comparisons between complex-contrast training and active control group (CG)

| Variables                     | Complex-contrast training group (n = 8) |                             | Active control group (CG) (n = 8) |                            | ANCOVA              |
|-------------------------------|-----------------------------------------|-----------------------------|-----------------------------------|----------------------------|---------------------|
|                               | Pre-test                                | Post-test                   | Pre-test                          | Post-test                  | p-value             |
|                               | Mean ± standard deviation               |                             | Mean ± standard deviation         |                            |                     |
| 15 m sprint (s)               | 2.71 ± 0.15                             | 2.61 ± 0.13 <sup>*M</sup>   | 2.69 ± 0.10                       | 2.69 ± 0.12 <sup>T</sup>   | 0.007 <sup>L</sup>  |
| 30 m sprint (s)               | 4.58 ± 0.22                             | 4.50 ± 0.20 <sup>*S</sup>   | 4.43 ± 0.17                       | 4.48 ± 0.15 <sup>S</sup>   | 0.015 <sup>L</sup>  |
| MBT (m)                       | 10.50 ± 0.6                             | 11.10 ± 1.0 <sup>*M</sup>   | 11.83 ± 1.17                      | 11.68 ± 1.09 <sup>T</sup>  | 0.034 <sup>L</sup>  |
| Standing Long Jump (m)        | 2.40 ± 0.10                             | 2.57 ± 0.13 <sup>*L</sup>   | 2.39 ± 0.15                       | 2.36 ± 0.15 <sup>S</sup>   | <0.001 <sup>L</sup> |
| CMJ height (cm)               | 36.50 ± 1.9                             | 45.30 ± 3.1 <sup>*VL</sup>  | 38.20 ± 4.1                       | 37.00 ± 3.2 <sup>S</sup>   | <0.001 <sup>L</sup> |
| Change of direction speed (s) | 6.01 ± 0.18                             | 5.44 ± 0.23 <sup>*S</sup>   | 5.97 ± 0.23                       | 6.01 ± 0.24 <sup>S</sup>   | <0.001 <sup>L</sup> |
| PT leg extension (right) (Nm) | 171.10 ± 22.1                           | 181.10 ± 21.7 <sup>*S</sup> | 187.50 ± 54.9                     | 189.50 ± 53.5 <sup>T</sup> | 0.001 <sup>L</sup>  |
| PT leg flexion (right) (Nm)   | 98.00 ± 8.1                             | 103.80 ± 9.1 <sup>*S</sup>  | 111.60 ± 29.6                     | 113.40 ± 27.0 <sup>T</sup> | 0.053 <sup>L</sup>  |
| PT leg extension (left) (Nm)  | 175.00 ± 23.2                           | 184.40 ± 22.8 <sup>*S</sup> | 202.50 ± 33.3                     | 204.30 ± 32.5 <sup>T</sup> | 0.022 <sup>L</sup>  |
| PT leg flexion (left) (Nm)    | 102.80 ± 17.9                           | 109.60 ± 18.3 <sup>*S</sup> | 110.50 ± 25.1                     | 111.90 ± 22.8 <sup>T</sup> | 0.009 <sup>L</sup>  |
| Maximum Power – RAST          | 555.20 ± 41.3                           | 594.40 ± 49.2 <sup>*L</sup> | 545.80 ± 65.8                     | 530.70 ± 71.0 <sup>S</sup> | 0.015 <sup>L</sup>  |
| Average Power – RAST          | 477.80 ± 36.4                           | 527.10 ± 32.7 <sup>*L</sup> | 487.60 ± 61.1                     | 476.30 ± 50.5 <sup>S</sup> | <0.001 <sup>L</sup> |

Note: CMJ – countermovement jump, g – Hedges' g, MBT – medicine ball throw, PT – peak torque, <sup>T</sup> – trivial effect size, <sup>S</sup> – small effect size, <sup>M</sup> – medium effect size, <sup>L</sup> – large effect size, <sup>VL</sup> – very large effect size, RAST – running-based anaerobic sprint test.

\* – significant difference from pre-test

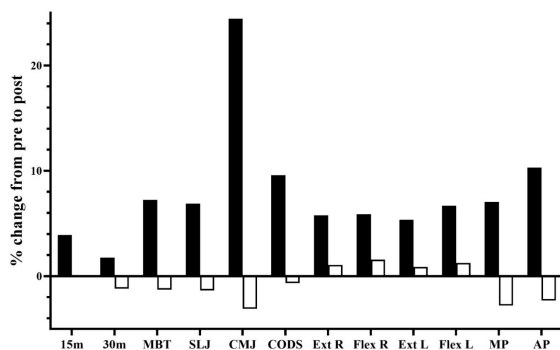


**Fig. 1.** Relative (%) change in dependent variables between pre- and post-intervention for the complex contrast training (black bars) and control group (white bars). Note: negative bars denote detrimental changes, CODS – change of direction speed, MBT – Medicine Ball Overhead Throw, SLJ – Standing Long Jump distance, CMJ – countermovement jump with arm swing height, Ext – knee extension for maximal torque, Flex – knee flexion for maximal torque, L – left, R – right, MP – Maximum Power, AP – Average Power.

level male soccer players. The findings suggest significant improvements in all the selected dependent variables after six weeks of CT compared to the active control group. Further, the magnitude of improvement from pre- to post-intervention was small for 30 m linear sprint and isokinetic strength (peak torque during knee flexion and extension of both legs), moderate for 15 m sprint and medicine ball throw, large for SLJ, maximum and average power during running-based anaerobic sprint test, and very large for CMJ and CODS.

These significant improvements in physical fitness performance after CT may be attributed to specific

neuromuscular adaptations that enhances the stretch-shortening cycle action. Furthermore, CT may have improved the energy transfer between the eccentric and concentric muscle actions, which allows better coordination as well as synchronization of the active muscle groups and thus improved and enhanced the motor skills (e.g., sprints, jumps, CODS) (Cronin et al., 2001). Moreover, CT has also been linked to hormonal adaptations (i.e., increased free testosterone) (Ali et al., 2019) and maximal strength development (Thapa et al., In press), which may positively enhance the physical fitness performance in soccer players (Wisløff et al., 2004). Other adaptation may have occurred at the cellular level (i.e., muscle fibre adaptations) that favors the strength-power generation (Bottinelli et al., 1996; Harridge et al., 1996; Stasinaki et al., 2015). For example, adding plyometric or power exercise with resistance exercise as in CT may help preserve the type IIx muscle fibres (Stasinaki et al., 2015) compared to resistance training alone (Adams et al., 1993). Although we did not measure the structural adaptations (e.g., leg muscle volume), however, previous studies have reported CT intervention to have increased the leg muscle volume in soccer players (Hammami et al., 2019; Hammami et al., 2017), and studies have shown that these structural adaptations after resistance or plyometric training do not interfere with neuromechanical adaptations (ACSM, 2009; Markovic & Mikulic, 2010). Therefore, it may be possible that the CT intervention may have induced structural adaptations that were not measured in our study.

We observed significant improvements in the 15 m (moderate) and 30 m (small) linear sprint performance favouring the CT intervention. These findings align with previous studies that reported improved linear sprint performance after CT intervention compared to a control condition (i.e., soccer training alone) during the pre-season period (Maio Alves et al., 2010). In addition, although Miranda et al. (2022) did not observe a significant interaction

effect with an active control group, however, within-group significant moderate improvements were reported for 10 m, 20 m (both moderate ES), and 30 m (small ES) linear sprint times from pre- to post-intervention similar to our study. These findings reflect that CT can induce improvements of moderate magnitude for the acceleration speed (15 m linear sprint) and small magnitude for the maximal speed (30 m linear sprint) during the pre-season period. Furthermore, there were large and very large improvements in SLJ and CMJ, respectively. Miranda et al. (2022) reported moderate improvement in CMJ (with a significant interaction effect against an active control group) during the pre-season period. The difference in the magnitude of improvement (moderate vs. very large) between the two studies may be due to the nature of the participants involved. For example, Miranda et al. (2022) included professional soccer players that competed in national-level competitions, whereas participants in our study were amateur university-level soccer players. It is plausible that participants in our study had a window of opportunity for improvement compared to the professional players. In addition, no previous CT study on soccer players reported SLJ making it challenging to compare. However, the SLJ may be an essential attribute in measuring the vertical-horizontal force-power complex of a soccer player. Therefore, CT may induce large to very large ES improvements in vertical and vertical-horizontal force-power complex during the pre-season period among amateur male soccer players.

We also observed a very large magnitude improvement in the CODS, which contrasts with findings from previous studies conducted during the pre-season period (Maio Alves et al., 2010; Miranda et al., 2022). For example, Maio Alves et al. (2010) conducted a six-week CT session with a training frequency of one and two sessions per week and found no improvement in the 5-0-5 agility test among elite soccer players. While Miranda et al. (2022) conducted a four-week CT with a training frequency of two sessions per week and reported no improvement in the Illinois agility test among professional soccer players. In both the previous studies (Maio Alves et al., 2010; Miranda et al., 2022), professional-elite level soccer players were involved, who may have possibly reached the maximum ceiling of improvement for CODS (e.g., playing soccer at the highest level may also have improved the CODS abilities). Furthermore, small ES improvements in the isokinetic strength of both legs' extensor and flexor muscles were reported after the six-week CT. Although previous pre-season CT studies on soccer players did not include isokinetic measurements, our findings align with a previous CT study conducted during the in-season period, which reported small to moderate ES improvements (Brito et al., 2014). Moreover, CT studies conducted on other populations (e.g., physically active participants) also reported small magnitude improvements in the isokinetic strength (G. Kumar, Pandey, Thapa, et al., 2023; Thapa & Kumar, 2023; Thapa, G. Kumar, et al., 2023). In addition, we also observed a moderate ES improvement in upper-body explosiveness (medicine ball throw). Although no previous CT study included assessment for upper-body explosives, Miranda et al. (2022) reported large ES improvement in the upper-body dynamic strength measured by 1RM bench press. Finally, we observed large ES improvements in maximum and average anaerobic power estimated with the running-

based anaerobic sprint test. While no previous CT study assessed anaerobic power using the running-based anaerobic sprint test, improvements in the test were observed with both complex-descending training and resistance training in female team sports athletes (Rathi et al., 2023).

Lastly, a few limitations of the study should be acknowledged. Firstly, stopwatch use to measure the timing-based measurements (e.g., linear sprints, CODS, running-based anaerobic sprint test). Although we obtained moderate test-retest reliability (interclass-correlation coefficient), the timing-based results should be used cautiously. Secondly, the study was conducted on amateur male soccer players during the preparatory period. Therefore, the finding of this study should not be extrapolated to other sex or training period of the competitive season. Thirdly, including biochemical variables (e.g., testosterone) could further help us understand the underlying mechanisms. Lastly, the sample size in the study was low. Although we performed a priori sample size estimation, a larger sample size would have been preferable. However, the results from this study may help generalize findings in the future (e.g., meta-analysis).

## Conclusion

In conclusion, a six-week CT intervention with a weekly training frequency of two sessions during the preparatory period may be sufficient to induce small ES improvement in maximal speed (30 m linear sprint) and isokinetic strength of extensor and flexor muscles of both legs, moderate ES improvement in acceleration speed (15 m linear sprint), and upper-body explosiveness (medicine ball throw), large ES improvement in horizontal jump (SLJ), anaerobic power (running-based anaerobic sprint test), and very large ES improvement in vertical jump (CMJ) and CODS.

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## ВПЛИВ КОНТРАСТНОГО ТРЕНУВАННЯ З ЧАСТОТОЮ ДВА ЗАНЯТТЯ НА ТИЖДЕНЬ НА РІВЕНЬ ФІЗИЧНОЇ ПІДГОТОВЛЕНОСТІ ЧОЛОВІКІВ-ФУТБОЛІСТІВ УНІВЕРСИТЕТСЬКОГО РІВНЯ

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

Реферат. Стаття: 8 с., 4 табл., 1 рис., 43 джерела.

**Метою цього дослідження було** порівняння впливу втручання у формі шеститижневого контрастного тренування, яке проводили двічі на тиждень протягом підготовчого періоду, на показники фізичної підготовленості чоловіків-футболістів університетського рівня.

**Матеріали та методи.** Для участі в дослідженні були вибрані шістнадцять гравців, яких випадковим чином розподілили до експериментальної групи або до групи активного контролю. Дані збирали на початковому етапі та після шеститижневого періоду тренувального втручання за результатами виконання таких тестів: прямолінійний біг на 15 м і 30 м, кидок медичного м'яча (КММ), стрибок у довжину з місця (СДМ), вертикальний стрибок із зустрічним рухом (ВСЗР), швидкість зміни напрямку (ШЗН), максимальний момент (обидві ноги) під час розгинання та згинання та анаеробний спринт-тест на основі бігу (АСТОБ).

**Результати.** За результатами аналізу було зареєстровано статистично значуще внутрішньогрупове покращення показників мірою величини від малої до дуже великої за всіма залежними змінними для експериментальної групи ( $p < 0,001 - 0,028$ ), але не для контрольної групи ( $p = 0,066 - 1,000$ ). Крім того, за результатами коваріаційного аналізу з використанням

оцінок попереднього тестування як коваріат було виявлено статистично значущі відмінності в оцінках після втручання для всіх залежних змінних, на користь групи контрастного тренування ( $p < 0,001-0,05$ ).

**Висновки.** Шеститижневе контрастне тренування з двома щотижневими заняттями протягом підготовчого періоду може бути достатнім для забезпечення невеликого покращення результатів у тестах «прямолінійний біг на 30 м» та «ізо-кінетична сила обох ніг», помірного покращення результатів у тестах «прямолінійний біг на 15 м» і КММ, значного покращення результатів у тестах СДМ, АСТОБ і дуже значного покращення результатів у тестах «вертикальний стрибок» (ВСЗР) і ШЗН.

**Ключові слова:** футбол, м'язова сила, тренування зі спротивом, пліометрична вправа, кондиційне тренування людей, спортивна результативність.

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ORIGINAL SCIENTIFIC ARTICLE

## EXPLORING THE IMPACT OF COMBINED THAI YOGA AND ELASTIC BAND EXERCISE ON PHYSICAL FITNESS AND EXERCISE CAPACITY IN OLDER PATIENTS WITH TYPE 2 DIABETES

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### Abstract

**Study purpose.** Although it is acknowledged that exercise can positively affect both physical and biochemical markers in older individuals with type 2 diabetes (T2DM), there are still uncertainties about the specific impacts of combining Thai yoga with an elastic band exercise in this population. The objective of the study was to assess the impact of a 12-week program involving Thai yoga combined with an elastic band exercise on the physical fitness and functional exercise capacity among older individuals with T2DM.

**Materials and methods.** A total of 42 participants, consisting of 20 men and 22 women with T2DM and a mean age of 64.6±3.6 years, were randomly assigned to two groups: the control group and the exercise group. The exercise group engaged in a daily regimen of Thai yoga combined with an elastic band exercise for 40 minutes, 5 days a week, over a 12-week period. In contrast, the control group maintained their regular routines. Physical fitness and functional exercise capacity were assessed both before and after the 12-week intervention.

**Results.** The exercise group showed significant reductions in body weight (58.7±11.9 vs. 58.0±12.0 kg), body mass index (24.2±3.0 vs. 23.9±3.0 kg/m<sup>2</sup>), waist circumference (33.6±3.6 vs. 33.1±3.6 in), and waist-hip ratio (0.90±0.06 vs. 0.89±0.06) ( $p < 0.001$ ). Additionally, there were notable improvements in physical fitness parameters, including hand grips, back strength, leg strength ( $p < 0.01$ ), and trunk flexibility ( $p < 0.001$ ). Functional exercise capacity, indicated by the 6-minute walk test and estimated peak oxygen consumption ( $p < 0.01$ ), also improved significantly.

**Conclusions.** Thai yoga combined with an elastic band exercise enhances physical fitness and functional exercise capacity in older individuals with T2DM. This improvement has the potential to enhance their cardiopulmonary performance. Consequently, this exercise regimen is considered a health alternative for older individuals with T2DM.

**Keywords:** exercise, yoga, resistance training, diabetes mellitus, exercise tolerance.

### Introduction

Aging is a natural process that unfolds in living organisms over time. The musculoskeletal system undergoes physiological changes in aging, including a decline in muscular strength, muscle endurance, flexibility, and balance, along with functional alterations in cardiopulmonary endurance. These changes contribute to reduced adaptability and an increase in functional impairment (Howe et al., 2011).

Various techniques are available to assess the physical fitness and exercise capacity of elderly individuals, encompassing muscle strength testing with dynamometry (Kim et al., 2022; Parraca et al., 2022), trunk flexibility assessment (Duray et al., 2020), the 6-minute walk test (6MWT) (American Thoracic Society, 2002), cardiopulmonary exercise testing (American Thoracic Society & American College of Chest Physicians, 2003), and the 2-minute step test (Poncumhak et al., 2023). Additionally, the elderly population may develop chronic diseases due to organ degeneration, particularly type 2 diabetes mellitus (T2DM). T2DM, a prevalent lifestyle disease driven by insulin resistance and insulin insufficiency,

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leads to persistent hyperglycemia and various cardiovascular consequences (Balaji et al., 2011).

Research indicates that exercise, coupled with a healthy diet, serves as a non-pharmacological treatment for older individuals with T2DM. Results show improvements in hemoglobin A1c (HbA1c), balance ability, body flexibility, and muscular strength (Xiao et al., 2017), suggesting that exercise can enhance the overall clinical characteristics and fitness levels of elderly T2DM patients. Lifestyle modification, particularly regular exercise, is recommended as a non-pharmacological therapeutic strategy for managing T2DM (Leite et al., 2020). The underlying principle is that working muscles enhance insulin sensitivity and promote glucose metabolism (Mogharnasi et al., 2019), positively affecting glycemic control, body composition, endothelial function, physical fitness, functional capacity, and self-reported well-being (Balaji et al., 2011; Barrows & Fleury, 2022; Fuentes-Lopez et al., 2021; Honda et al., 2021).

Yoga, a low-impact, weight-bearing exercise suitable for the elderly, has demonstrated benefits in enhancing muscle strength, body balance, flexibility, and cardiovascular endurance (American College of Sports Medicine, 2013; Phoosuwan et al., 2021). It also regulates hormone production, promoting movement (McCaffrey et al., 2014; Posadzki et al., 2009), increasing metabolism, and lowering blood pressure (Satyanarayana et al., 2013). Yoga has been reported to improve bone health, and reduce body mass index (BMI), body fat, and blood sugar (Balk & Bernardo, 2011; Chen et al., 2007; Hovsepian et al., 2013), enhance flexibility, muscle strength, blood circulation, and oxygen uptake, and reduce blood glucose levels, particularly in chronic diseases like T2DM (Angadi et al., 2017). Previous studies suggest that yoga is a non-pharmacological therapeutic option for improving the quality of life in older adults with T2DM (Balk & Bernardo, 2011; Phoosuwan et al., 2021).

Resistance training, utilizing muscular strength against resistance, is another form of exercise (Bauer et al., 2021). Elastic bands, cost-effective and space-efficient, are suitable for home or group use. Band characteristics, such as elongation and thickness, influence the force produced (Church et al., 2010). Research indicates that resistance exercise with elastic bands can lower HbA1c, enhance insulin sensitivity (Phillips & Winett, 2010), boost strength (Church et al., 2010; García et al., 2019), and improve the quality of life (Reid et al., 2010) in T2DM patients, making them a valuable alternative exercise for elderly individuals with T2DM.

While previous studies have separately explored the benefits of yoga or resistance training with an elastic band in T2DM patients and the elderly (Balaji et al., 2011; Leite et al., 2020; Pratiwi & Hasinuddin, 2018), the combination of these exercises on physical fitness and functional exercise capacity remains understudied. The present study aims to investigate the impact of a 12-week Thai yoga combined with an elastic band exercise on anthropometry, physical fitness, and functional exercise capacity in older individuals with T2DM.

## Materials and methods

### Study participants

Participants were recruited from diverse community areas in Phayao Province, Thailand. Approval for this

experiment was obtained from the University of Phayao Human Ethics (the approval number is 2/153/62). Before participation, each individual provided written informed consent after being informed about the study protocols, risks, and benefits. The Declaration of Helsinki guided the conduct of this investigation.

A total of 42 T2DM patients (20 men and 22 women, age range: 60-72 years, mean age:  $64.6 \pm 3.6$  years) were recruited. Selection criteria included age between 60-80 years, either gender, a diagnosis of T2DM (fasting blood sugar levels  $\geq 126$  mg/dL), no previous experience with elastic band exercise or other exercise programs for at least 6 months before the study, no history of acute medical problems or emergency department visits, no hospitalizations resulting from T2DM complications in the past 3 months, and no surgery on the cardiovascular system or at least three falls in the 12 months before enrolling. Exclusion criteria were a history of cardiovascular or respiratory illness, neuromuscular or musculoskeletal diseases affecting postural control, pain of more than 3 degrees, or vision deficits influencing the study's outcome. The participant flow through the study is illustrated in Fig. 1.

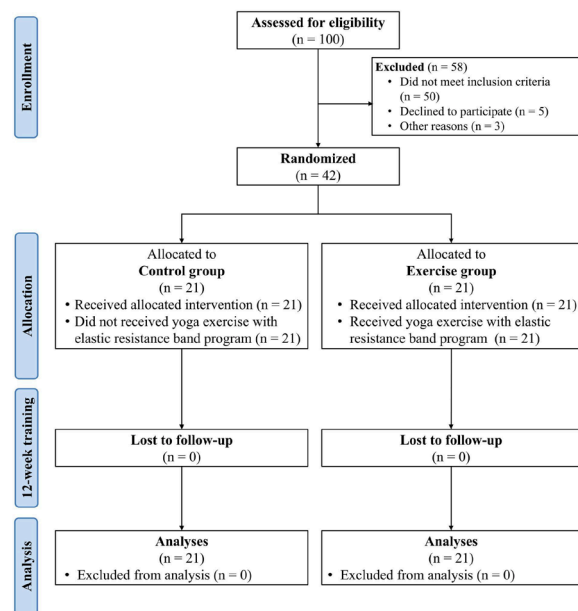


Fig. 1. CONSORT flow diagram of participants through the intervention

### Study organization

Participants underwent a 2-week, 3-day familiarization program of Thai yoga combined with an elastic band exercise program conducted by the instructor before the testing session. The participants were randomly assigned to either the control group (n = 21) or the exercise group (n = 21). The exercise group engaged in a 40-minute Thai yoga combined with an elastic band exercise program following the procedure outlined in the previous study (Promsrisuk et al., 2023), divided into a 5-minute warm-up phase, a 30-minute exercise phase, and a 5-minute cool-down phase. The control group did not engage in any exercise activities. Throughout the 12-week study, all patients continued their diabetes medications regularly.

## Outcome measurements

### Anthropometric profiles

Anthropometric data, including height, weight, waist circumference (WC), hip circumference (HC), and waist-hip ratio (WHR), were directly gathered by the researcher. Body weight was assessed without shoes and in light clothing using Tanita electronic scales, and height was measured with a Stadiometer. BMI was calculated using the standard formula: weight (kilograms)/height (meters) squared.

### Back and leg strength test

A strength dynamometer measured back and leg isometric strength according to a standard assessment protocol (Bandinelli et al., 1999). In brief, participants were instructed to stand on the dynamometer's base with feet shoulder-width apart and both hands on the mid-thigh handle (knee flexion angle of roughly 110 degrees) (Dawes et al., 2019). Then, the participants attempted to straighten the legs and keep the arms straight without bending the back, while pulling as hard as possible on the chain. The highest test score from two trials was recorded.

### Trunk flexibility test

Trunk flexibility was measured by the sit and reach test (Clark, 1989). Participants sat on the floor with their feet against the testing box, reaching forward along the measuring board while holding their legs straight. The highest test score from two trials was recorded.

### The 6-minute walk test

The 6MWT, recommended by the American Thoracic Society, evaluated functional exercise capacity (Carter et al., 2003; Enright et al., 2003; Rocha et al., 2022). Participants were instructed to sit for 10 minutes while vital signs were recorded. Leg fatigue and dyspnea scores were measured at the start and completion of the walk using the Borg rating of perceived exertion. Participants were instructed to walk as far as possible along a flat hallway designated with a 30-meter track pathway without running within the allocated 6 minutes (Whittaker et al., 2019). The total distance of the 6MWT (6MWD) was calculated and used for estimating peak oxygen uptake ( $\text{VO}_{2\text{peak}}$ ). The estimated  $\text{VO}_{2\text{peak}}$  was determined using the formula: estimated  $\text{VO}_{2\text{peak}} = 4.948 + (0.023 \times 6\text{MWD})$  (Ross et al., 2010).

### Statistical analysis

The statistical analysis was performed using STATA version 14.0. Data are presented as means  $\pm$  standard deviation. Normality was assessed using the Shapiro-Wilk test. Paired t-tests compared data within control and exercise groups before and after 12 weeks, while unpaired t-tests compared control and exercise groups. Non-normally distributed data within groups were evaluated with the Wilcoxon signed-rank test and between groups with the Wilcoxon rank-sum test. The significance level was set at  $p < 0.05$ .

## Results

The analysis covered the baseline characteristics and anthropometry of the 42 elderly patients with T2DM, as outlined in Table 1. Age, gender, body weight, height, BMI, WC, HC, WHR, and oxygen saturation ( $\text{SpO}_2$ ) showed no significant differences between the two groups. After a 12-week training period, the exercise group exhibited a substantial reduction in body weight ( $58.7 \pm 11.9$  vs.  $58.0 \pm 12.0$  kg,  $p < 0.001$ ), BMI ( $24.2 \pm 3.0$  vs.  $23.9 \pm 3.0$  kg/m<sup>2</sup>,  $p < 0.001$ ), WC ( $33.6 \pm 3.6$  vs.  $33.1 \pm 3.6$  in,  $p < 0.001$ ), and WHR ( $0.90 \pm 0.06$  vs.  $0.89 \pm 0.06$ ,  $p < 0.001$ ) (Table 1). Furthermore, neither the control nor the exercise group demonstrated any significant changes in HC compared to their baseline.

The physical fitness and functional exercise capacity in the control and exercise groups are presented in Table 2. Physical fitness (hand grips, back and leg strength, and trunk flexibility) and functional exercise capacity (6MWD and estimated  $\text{VO}_{2\text{peak}}$ ) did not exhibit statistically significant differences between the control group and the exercise group at the baseline (Table 2). Following the 12-week training period, the exercise group exhibited a statistically significant improvement in physical fitness, as evidenced by their hand grips ( $21.9 \pm 5.6$  vs.  $25.3 \pm 5.7$  kg,  $p < 0.01$ ), back strength ( $52.0 \pm 15.4$  vs.  $55.4 \pm 15.5$  kg,  $p < 0.01$ ), leg strength ( $63.2 \pm 19.6$  vs.  $66.2 \pm 18.7$  kg,  $p < 0.01$ ), and trunk flexibility ( $17.2 \pm 2.4$  vs.  $20.2 \pm 2.2$  cm,  $p < 0.001$ ) (Table 2, Fig. 2). Similarly, the exercise group demonstrated a significant increase in functional exercise capacity, including 6MWD ( $344.3 \pm 38.8$  vs.  $372.9 \pm 60.0$  m,  $p < 0.01$ ) and estimated  $\text{VO}_{2\text{peak}}$  ( $28.7 \pm 2.7$  vs.  $28.3 \pm 2.8$  ml/kg/min,  $p < 0.01$ ) (Table 2, Fig. 3). However, there were no significant differences in any physical fitness or functional exercise capacity between the two groups after the 12-week duration. In the control group, there were also no significant differences between the baseline and after 12 weeks (Table 2).

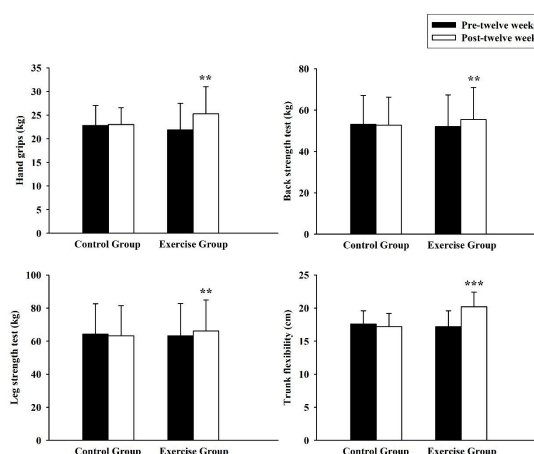


Fig. 2. Physical fitness during pre- and post-twelve weeks in control and exercise groups. \*\* $p < 0.01$  and \*\*\* $p < 0.001$  to within-group comparison (before vs. after the 12-week period)

## Discussion

The present study indicated that the combination of Thai yoga and elastic band exercise significantly improves body weight, BMI, WC, and WHR in elderly patients with T2DM.

**Table 1.** The measures of basal characteristics and anthropometry profiles were assessed during pre- and post-twelve weeks in control and exercise groups

| Variables                | Control group (n = 21) |             | Exercise group (n = 21) |                 |
|--------------------------|------------------------|-------------|-------------------------|-----------------|
|                          | Pre-                   | Post-       | Pre-                    | Post-           |
| Genders:                 |                        |             |                         |                 |
| Male                     | 10                     |             | 10                      |                 |
| Female                   | 11                     |             | 11                      |                 |
| Age (years)              | 64.90 ± 3.6            |             | 64.3 ± 3.7              |                 |
| Height (cm)              | 155.10 ± 5.6           |             | 155.1 ± 9.01            |                 |
| Weight (kg)              | 57.50 ± 8.5            | 57.80 ± 8.6 | 58.7 ± 11.9             | 58.00 ± 12.0*** |
| BMI (kg/m <sup>2</sup> ) | 23.80 ± 2.7            | 23.90 ± 2.7 | 24.2 ± 3.0              | 23.90 ± 3.0***  |
| WC (in)                  | 33.40 ± 2.9            | 33.60 ± 2.8 | 33.6 ± 3.6              | 33.10 ± 3.6***  |
| HC (in)                  | 37.90 ± 1.9            | 37.90 ± 2.1 | 37.2 ± 2.4              | 37.20 ± 2.5     |
| WHR                      | 0.88 ± 0.1             | 0.88 ± 0.0  | 0.9 ± 0.1               | 0.89 ± 0.1***   |
| SpO <sub>2</sub> (%)     | 98.10 ± 0.8            | 98.30 ± 0.6 | 98.2 ± 0.8              | 98.40 ± 0.6     |

Data are expressed as mean ± SD. BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio; SpO<sub>2</sub>: pulse oxygen saturation. \*\*\*Significant p < 0.001 before vs. after the 12-week period

**Table 2.** The measures of physical fitness and functional exercise capacity were assessed during pre- and post-twelve weeks in control and exercise groups

| Variables                        | Control group (n = 21) |              | Exercise group (n = 21) |                |
|----------------------------------|------------------------|--------------|-------------------------|----------------|
|                                  | Pre-                   | Post-        | Pre-                    | Post-          |
| Hand grips (kg)                  | 22.8 ± 4.2             | 23.0 ± 3.6   | 21.9 ± 5.6              | 25.3 ± 5.7**   |
| Back strength test (kg)          | 53.1 ± 14.0            | 52.7 ± 13.6  | 52.0 ± 15.4             | 55.4 ± 15.5**  |
| Leg strength test (kg)           | 64.2 ± 18.4            | 63.2 ± 18.3  | 63.2 ± 19.6             | 66.2 ± 18.7**  |
| Trunk flexibility (cm)           | 17.6 ± 2.0             | 17.2 ± 2.0   | 17.2 ± 2.4              | 20.2 ± 2.2***  |
| 6MWD (m)                         | 342.9 ± 36.8           | 340.5 ± 40.0 | 344.3 ± 38.8            | 372.9 ± 60.0** |
| VO <sub>2</sub> peak (ml/kg/min) | 28.7 ± 2.7             | 28.3 ± 2.8   | 28.3 ± 3.5              | 30.1 ± 4.2**   |

Data are expressed as mean ± SD. 6MWD: six-minute walk distance; VO<sub>2</sub>peak: peak oxygen uptake. \*\*Significant p < 0.01, p < 0.001 before vs. after the 12-week period

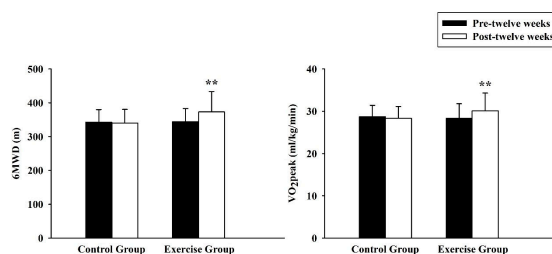


**Fig. 3.** Six-minute walk distance (6MWD) and peak oxygen uptake (VO<sub>2</sub>peak) during pre- and post-twelve weeks in control and exercise groups. \*\*p < 0.01 to within-group comparison (before vs. after the 12-week period)

The findings of this study align with earlier research, such as the implementation of yoga asanas and pranayama for 60 minutes daily over a consecutive 12-week period, resulting in reductions in body weight, BMI, and WHR in T2DM patients (Balaji et al., 2011; Barrows & Fleury, 2022). The mechanisms underlying the effects of yoga on body weight, BMI, WC, and WHR remain unclear, but potential

explanations include direct rejuvenation or regeneration of pancreatic beta cells (Raveendran et al., 2018; Raveendran et al., 2018; Shantakumari et al., 2013), neuroplasticity promotion affecting the hypothalamic-pituitary-pancreas axis (Subba et al., 2021), and redistribution of fat from the waist to central abdominal fat during yoga practice (Shantakumari et al., 2013). Furthermore, increased total blood flow during yoga may influence glucose uptake in muscle cells, contributing to reduced lean body mass and skin fold thickness and subsequent reductions in WHR (Balaji et al., 2011). Elastic band exercise has shown benefits for T2DM patients by improving anthropometry, including body weight, BMI, WC, and WHR (Barrows & Fleury, 2022; Oh et al., 2017; Park et al., 2016). Elastic band exercise training for 40 to 60 minutes per session, 2 daily for 5 days per week over 12 weeks, has demonstrated positive effects on anthropometry and body composition in women with short-long-duration T2DM (Park et al., 2016).

The integration of yoga and elastic band exercise has shown positive effects in reducing HbA1c levels, managing blood sugar and lipids (García et al., 2019), and improving cardiovascular health along with the metabolism-lipolysis

process (Barrows & Fleury, 2022). Moreover, elastic band resistance exercise with modified Thai yoga in T2DM patients has shown reductions in blood glucose, HbA1c, oxidative stress, and increases in antioxidants and pulmonary function (Promsrisuk et al., 2023). The possible mechanism may be related to proinflammatory cytokines, specifically tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ) and interleukin-6 (IL-6), released by visceral fat, which may contribute to obesity-related insulin resistance (Kirwan et al., 2017). Decreased insulin resistance, associated with changes in adiposity, cholesterol levels, and increased expression of glucose transporter type 4 (Amanat et al., 2020), may improve disease status and quality of life (Stanford & Goodyear, 2014). Additionally, increased muscle mass has been shown to help reduce insulin resistance in elderly adults with diabetes and cardiovascular disease (Stanford & Goodyear, 2014). Furthermore, it diminishes oxidative stress, elevates antioxidant markers, and improves cardiopulmonary function in individuals with T2DM (Promsrisuk et al., 2023).

This study revealed a significant improvement in physical fitness following the 12-week regimen of Thai yoga and elastic band exercise, with hand grip strength, back strength, leg strength, and trunk flexibility increasing by 15.5%, 6.5%, 4.7%, and 17.7%, respectively. Moreover, the exercise program enhanced functional exercise capacity, with an 8.3% increase in the 6MWD and a 6.4% increase in estimated  $\text{VO}_2\text{peak}$  compared to baseline. These findings are in line with earlier research by Herriott and colleagues (Herriott et al., 2004), demonstrating that 8 weeks of combined resistance and flexibility training (50-70% 1RM of resistance, three days per week, three sets of 8-12 repetitions for each of the eight exercises), along with standard flexibility exercises (10-30 seconds for each), improved joint range of motion without affecting  $\text{VO}_2\text{peak}$  in elderly patients with T2DM (Herriott et al., 2004). Interestingly, compared to either aerobic or resistance exercise alone, combination training demonstrated a more positive impact on glycemic control (Raveendran et al., 2018; Raveendran et al., 2018). Several studies have reported that strength exercise with elastic bands and aerobic exercise can enhance anthropometric and biochemical variables by improving muscle mass, glycemic control, and intra-myocytic fat accumulation (Amanat et al., 2020; García et al., 2019; Kirwan et al., 2017). Furthermore, a previous study indicated that combining aerobic and resistance exercise holds greater therapeutic potential for improving insulin sensitivity than aerobic exercise alone in T2DM patients (AminiLari et al., 2017). Therefore, it demonstrates that combined training is an effective exercise approach for enhancing physical fitness and contributing to optimal functional exercise capacity ( $\text{VO}_2\text{peak}$ ) in older individuals with T2DM.

This exercise combination offers an additional option for improving the health and well-being of elderly individuals with T2DM. However, it is important to acknowledge certain limitations in the study, such as the lack of detailed information on individual dietary variances, nutritional knowledge, lifestyle choices, and dietary modifications, which should be addressed in future research.

## Conclusions

The present study indicates that a 12-week regimen of Thai yoga combined with an elastic band exercise emerges

as a health-promoting routine capable of significantly enhancing physical fitness, functional exercise capacity, and anthropometric parameters in elderly patients with T2DM. Consequently, the results suggest that integrating Thai yoga with an elastic band exercise holds promising health benefits and may serve as a viable alternative exercise program for older individuals with T2DM.

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## Conflict of interest

The authors affirm that they do not have any conflicts of interest.

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## ВИВЧЕННЯ ВПЛИВУ КОМБІНОВАНИХ ВПРАВ ІЗ ТАЙСЬКОЇ ЙОГИ ТА ВПРАВ ЗІ СТІЧКОВИМ ЕСПАНДЕРОМ НА ФІЗИЧНУ ПІДГОТОВЛЕНІСТЬ І ЗДАТНІСТЬ ПЕРЕНОСИТИ ФІЗИЧНЕ НАВАНТАЖЕННЯ В ЛІТНІХ ПАЦІЄНТІВ ІЗ ЦУКРОВИМ ДІАБЕТОМ 2 ТИПУ

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

Реферат. Стаття: 8 с., 2 табл., 3 рис., 51 джерело.

**Мета дослідження.** Незважаючи на загальне визнання факту, що фізичні вправи можуть позитивно впливати як на фізичні, так і на біохімічні показники в людей похилого віку із цукровим діабетом 2 типу (ЦД2Т), досі існує невизначеність щодо конкретних наслідків комбінованого виконання вправ із тайської йоги та вправ зі стрічковим еспандером для цієї популяції. Метою цього дослідження було оцінити вплив 12-тижневої програми, яка включає вправи з тайської йоги в поєднанні з вправами зі стрічковим еспандером, на фізичну підготовленість і функціональну здатність переносити фізичне навантаження в літніх осіб із цукровим діабетом 2 типу.

**Матеріали та методи.** У дослідженні брали участь загалом 42 учасники, серед яких було 20 чоловіків та 22 жінки із ЦД2Т середнім віком  $64,6 \pm 3,6$  року, яких випадковим чином розподілили на дві групи: контрольну групу та групу фізичних вправ. Група фізичних вправ займалася за розпорядком дня, що передбачав виконання вправ із тайської йоги в поєднанні з вправами зі стрічковим еспандером протягом 40 хвилин, 5 днів на тиждень, протягом 12 тижнів. На відміну від них, контрольна група дотримувалася свого звичайного розпорядку дня. Фізичну підготовленість і функціональну здатність переносити фізичне навантаження оцінювали як до, так і після 12-тижневого втручання.

**Результати.** У групі фізичних вправ спостерігалось статистично значуще зниження показників маси тіла ( $58,7 \pm 11,9$  проти  $58,0 \pm 12,0$  кг), індексу маси тіла ( $24,2 \pm 3,0$  проти  $23,9 \pm 3,0$  кг/м<sup>2</sup>), окружності талії ( $33,6 \pm 3,6$  проти  $33,1 \pm 3,6$  дюйма), а також співвідношення окружності талії та окружності стегон ( $0,90 \pm 0,06$  проти  $0,89 \pm 0,06$ ) ( $p < 0,001$ ). Крім того, спостерігалось помітне покращення параметрів фізичної підготовленості, включаючи силу стиснення кисті, силу спини, силу ніг ( $p < 0,01$ ) і гнучкість тулуба ( $p < 0,001$ ). Функціональна здатність переносити фізичне навантаження, яку показує тест на 6-хвилинну ходьбу та розрахункове пікове споживання кисню ( $p < 0,01$ ), також статистично значуще покращилась.

**Висновки.** Тайська йога у сполученні з вправами зі стрічковим еспандером покращує фізичну підготовленість і функціональну здатність переносити фізичне навантаження в літніх людей із цукровим діабетом 2 типу. Це покращення має потенціал для покращення їхньої серцево-легеневої діяльності. Отже, цей режим фізичних вправ вважається спортивно-оздоровчою альтернативою для літніх осіб із ЦД2Т.

**Ключові слова:** вправа, йога, тренування зі спротивом, цукровий діабет, здатність переносити фізичне навантаження.

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ORIGINAL SCIENTIFIC ARTICLE

## EFFECT OF SPEED AGILITY QUICKNESS AND CIRCUIT TRAINING ON LIPID PROFILE OF SOCCER PLAYERS: AN OBSERVATIONAL STUDY

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### Abstract

**Study purpose.** This observational study aims to investigate the impact of a Speed Agility Quickness (SAQ) and Circuit training program on the lipid profile of soccer players. The study focuses on analyzing changes in high-density lipoprotein (HDL), low-density lipoprotein (LDL), and very-low-density lipoprotein (VLDL) cholesterol concentrations after the intervention.

**Materials and methods.** The study involved a total of 30 elite soccer players with the mean (Sd) of age 16.93 (1.20) years; stature 5.66 (0.16) feet; weight 59.93 (5.47) kg. All the players selected for the study were registered players of Poloi Academy, Imphal, Manipur. The participants were divided into two groups, i.e., the SAQ and Circuit groups, and underwent a 12 weeks SAQ and Circuit training program respectively, which was conducted 3 days per weeks. Blood samples were collected before and after the intervention to measure HDL, LDL, and VLDL cholesterol levels. The participants' lipid profiles were assessed using standard laboratory techniques.

**Results.** The results of this study demonstrated significant changes in the lipid profiles of the elite soccer players following the SAQ and Circuit training program. The intervention resulted in a significant increase in HDL cholesterol levels. Simultaneously, there was a substantial decrease in LDL and VLDL cholesterol concentrations.

**Conclusions.** The increase in HDL cholesterol and reduction in LDL and VLDL cholesterol levels indicate a potential decrease in the risk of cardiovascular diseases and related health issues. Considering the importance of lipid metabolism in athletic performance and overall well-being, this study provides valuable insights for coaches, athletes, and sports professionals in designing targeted training regimens to optimize cardiovascular health among soccer players. However, further research with larger sample sizes and long-term follow-ups is warranted to validate and generalize these findings across diverse populations and sports disciplines.

**Keywords:** HDL, LDL, VLDL, SAQ, Cholesterol, Circuit.

### Introduction

Lipid profile and its metabolism plays a crucial role in the body's overall health and energy balance. It involves the complex processes of lipid digestion, absorption, transport, and utilization, which are regulated by various factors, including diet, physical activity, and genetics (Farooque, Mitra, et al., 2023). In recent years, there has been a growing interest in exploring the impact of different exercise modalities on lipid metabolism to optimize overall health and athletic performance. Blood lipoproteins are formed

by various amounts of cholesterol (C), triglycerides (TGs), phospholipids, and apolipoproteins (Apos). ApoA1 is the major structural protein of high-density lipoprotein (HDL), accounting for ~70% of HDL protein, and mediates many of the antiatherogenic functions of HDL (Farooque, Das, et al., 2023). Conversely, ApoB is the predominant low-density lipoprotein (LDL) Apo is an indicator of circulating LDL, associated with higher coronary heart disease (CHD) risk (Muscella et al., 2020a). During exercise and sports activities, both fat and carbohydrates play an important role as primary sources of fuel for the body (Azmi & Kusnanik, 2018). The body relies on four major internal sources of energy during exercise: glucose in the bloodstream, derived from liver glycogenolysis; free fatty acids (FFAs) released from adipose

tissue lipolysis and the hydrolysis of triacylglycerol (TG) in very low-density lipoproteins (VLDL-TG); muscle glycogen stored within the skeletal muscles; and intramyocellular triacylglycerols (IMTGs) present within the muscle fibers (Rui, 2014; Muscella et al., 2020a).

During low-to-moderate intensity exercises and prolonged physical activity, the majority of energy demands for skeletal muscles are met through the oxidation of fatty acids (FA), with a minor contribution from glucose oxidation (Marandi et al., 2013; Hargreaves & Spriet, 2020). As exercise intensity increases, the reliance on fat as an energy source continues to grow until it reaches approximately 60-65% of  $\dot{V}O_2$ max or 74% of the maximum heart rate (Prins et al., 2023). As exercise intensity escalates, there is a notable alteration in the mobilization and utilization of energy substrates (Coyle, 1995). This change involves an increase in the relative reliance on carbohydrate oxidation to meet energy demands, accompanied by a simultaneous decrease in the relative contribution of fat oxidation. This shift in substrate utilization occurs as physical activity transitions from moderate to high intensity (Ramadoss et al., 2022). During the course of exercise, the source of fatty acids (FA) utilized also undergoes changes. At 25% of  $\dot{V}O_2$ max, the oxidized fat mainly comes from plasma FA (Farooque, Mitra, et al., 2023). However, as exercise intensity reaches 65% of  $\dot{V}O_2$ max, the contribution of plasma FA decreases, and there is a notable increase in the oxidation of intramyocellular triacylglycerols (IMTG), providing approximately half of the FA used for overall fat oxidation moderate-intensity exercise, the heightened demand for FAs is met through increased lipolysis of adipose tissue triacylglycerols (TGs) (Purdum et al., 2018; Mika et al., 2019). This rise in adipose tissue TG lipolysis, and potentially IMTG utilization, is mediated by an augmented response of catecholamines to exercise (Liu et al., 2020). During physical exercise, both lipids and carbohydrates are oxidized at the same time, although their proportional contributions as fuel sources are controlled by a variety of circumstances (Brun et al., 2022; Pi et al., 2023). These variables include the type of exercise undertaken, the length of the exercise session, and the level of physical activity (Gordon et al., 2014a). Based on these characteristics, the body dynamically modifies its utilization of fats and carbs to fulfil the energy demands of the specific exercise or sport being performed (Mul et al., 2015).

Speed, agility, and quickness (SAQ) training, along with circuit training, have gained popularity as effective exercise approaches to enhance various aspects of physical fitness, such as cardiovascular endurance, muscular strength, and agility (Farooque, Das, et al., 2023). These training methods involve high-intensity, intermittent activities that challenge multiple physiological systems simultaneously, potentially influencing lipid metabolism. However, limited research has been conducted to investigate the specific effects of SAQ and circuit training on lipid metabolism. Understanding the relationship between exercise modalities and lipid metabolism is essential as lipid abnormalities are a significant risk factor for various metabolic disorders, including obesity, dyslipidemia, and cardiovascular diseases. Identifying exercise protocols that can positively impact lipid metabolism may offer valuable insights for developing targeted exercise interventions to prevent and manage these health conditions.

Therefore, this cross-sectional study aims to examine the potential effects of Speed, Agility, and Quickness training and circuit training on lipid metabolism over elite soccer player of Manipur. By elucidating the relationship between exercise modalities and lipid metabolism, this study seeks to contribute valuable information to the fields of exercise science, sports performance, and public health. Furthermore, the findings may have practical implications for exercise prescription and designing personalized training programs aimed at optimizing lipid profiles and promoting overall health and well-being.

## Materials and method

### Study participants

A purposive sampling technique was used to select the total no. of thirty (N=30) under 19 player who are currently participated in different junior national level tournament i.e., SM Cup, SGFI. The age range of the selected players were between U-16 to U-19 with the mean (Sd) of age 16.93 (1.20) years; stature 5.66 (0.16) feet; weight 59.93 (5.47) kg. All the players selected for the study were registered player of Poloi Academy, Imphal, Manipur. In addition of the above they are currently participating in different national and state level tournaments. The study protocol was retained for every participant. All the selected players for the study underwent the Speed, Agility, Quickness (SAQ) and Circuit training for 12 weeks after the baseline data collection. The study was conducted in June-October 2022. The Institutional Human Ethical Committee approved the protocol adopted for the study (Ref: TU/IHEC/3/1/22) invariant with the necessity for human experimentation per the declaration of Helsinki. Further the selected players were divided into two different groups for further treatment and to follow up the design of the study. As the study directed towards the two group of SAQ and Circuit training total players were divided in fifteen (n=15) each for two different group. SAQ group were given the name of Group I and Circuit group were name as Group II. Group I consisted of fifteen (n = 15) with the mean (Sd) of age 17.00 (1.31) years, weight 61.87 (5.94) kg, height 5.67 (0.17) ft. Group II comprised of fifteen (n = 15) with the mean (Sd) of 16.87 (1.13) years, weight 57.88 (4.22) kg, height 5.64 (0.15) ft. After the baseline collection of data both the group underwent the training of 12 weeks in the training ground of Poloi Academy under same environment condition. Training was given after the baseline collection of data on the following variables of lipid such as High-density lipoprotein, Low density lipoprotein, very low-density lipoprotein. Further the training was continued for 72 days as a formal procedure of the study (Farooque, Das, et al., 2023). The data were collected from both the group by following proper protocol of collection procedure.

### Training protocol

The training program consist of SAQ and Circuit training Group. The training was given in the morning start from 7.00 am and continued till 8.30 am (warming up and limbering down). The training program were conduct 3 days per week for whole duration of 12 weeks (Luo et al., 2023). In every day training session, the work out was lasted for

one (01) hour, which excluded warming up and limbering down. The recovery time in between of repetition was incomplete and in between of sets was complete recovery. The progressive load principle was adopted.

#### Procedure of data collection

All the players were informed to be seated with back support or supine if they were anxious or had a history of vasovagal reaction. They were asked to support the supinated forearm on a comfortable surface during the blood sample collection before and after the training. Five ml of blood in two test tubes from the antecubital vein were collected from each player for biochemical study (Kostrzewa-Nowak et al., 2015). The collected blood sample then proceeded to the biochemical analysis (SRL Diagnostic Centre, Imphal Manipur). Further the data has been uploaded to Excel for different analysis and inference.

#### Statistical analysis

Experimental data were further analyzed descriptively for explaining the various status of presented sample in the study. Pair sample -test were employed to find the significance difference from pre to post training of SAQ and Circuit group. The level of significance was set at 0.05.

#### Results

The level of changes in the HDL after SAQ training on the soccer player has been shown in table 1 which indicates the significant changes in the mean value and SD from pre ( $49.26 \pm 7.54$ ) to post ( $56.13 \pm 7.22$ ) respectively. Further the result has been compared by using pair sample t test which revealed the t value of 7.92 which significant at .000 at significance level of 0.05 and the determinative power of significant difference in this analysis was 100%. Additionally, LDL and VLDL has also shown the significant reduction from their pre data to post data which the positive determination in the hormonal changes of our body and indicating the positive sign of the training effect. The results

in the table 1 shown a reduction value in mean value and SD in both variables i.e., mean and SD value of pre and post for LDL were ( $78.86 \pm 13.96$ ) and ( $69.66 \pm 13.82$ ) whereas the pre and post value of VLDL were ( $20.33 \pm 13.69$  and  $15.86 \pm 6.34$  respectively). In the light of comparison among the pre and post HDL have shown a significant difference with a t value of 5.45 that is significant at  $p=0.000$  but the VLDL have shown an insignificant difference when compared to pre and post data with a  $p=0.104$  which is not significant at 0.05 level.

Evident shown by the table 2 on HDL shown a significant increase from pre to post ( $54.60 \pm 8.50$ ) and ( $60.53 \pm 10.22$ ). Further shown a significant t value of 9.93 in compare to pre and post which is significant at 0.05 level. The study shown a significant reduction in the mean value from pre to post in case of LDL which shown positive effect on the changes of lipid parameters. The mean value of LDL from pre to post were ( $65.53 \pm 21.97$ ) and ( $57.80 \pm 17.73$ ) respectively. The result has been compared to find the significant difference and the t value of 3.19 was observed with significant value of  $p=0.006$ . the mean value and Sd observed for pre and post of VLDL were ( $16.20 \pm 4.57$ ) and ( $13.73 \pm 4.16$ ) respectively. In addition, significant difference was also observed at 0.05 level of significance.

#### Discussion

The result of the study shows that implementation of 12 weeks SAQ and Circuit training on young football players shows and increased in the concentration and production of HDL, and decreased in LDL and VLDL. The increase in HDL and decrease in LDL and VLDL levels indicate improved cardiovascular health, which can contribute to better athletic performance and long-term well-being. In support of the present study, (Muscella et al., 2020b) reported over a study involving 10 men aged between 46 and 62 years to investigate the effects of endurance exercise training on plasma lipoproteins. The participants underwent a training program consisting of exercise at intensities ranging from 50% to 85% of their maximum oxygen consumption ( $VO_{2max}$ ) for 3 to 5 days per week over a period of 29 to 57 weeks. The results of the study revealed several “antiatherogenic”

**Table 1.** Comparison on the effect of SAQ training program on lipid Profile

| Parameters | N  | Test      | Mean  | SD    | SEM  | t-Value | p-Value | % of Change |
|------------|----|-----------|-------|-------|------|---------|---------|-------------|
| HDL        | 15 | Pre test  | 49.26 | 7.54  | 1.94 | 7.92    | .000    | 15%         |
|            |    | Post test | 56.13 | 7.22  | 1.86 |         |         |             |
| LDL        | 15 | Pre test  | 78.86 | 13.96 | 3.60 | 5.45    | .000    | 12%         |
|            |    | Post test | 69.66 | 13.82 | 3.57 |         |         |             |
| VLDL       | 15 | Pre test  | 20.33 | 13.69 | 3.53 | 1.74    | .104    | 14%         |
|            |    | Post test | 15.86 | 6.34  | 1.63 |         |         |             |

**Table 2.** Comparison on the effect of Circuit training program on lipid Profile

| Parameters | N  | Test      | Mean  | SD    | SEM  | t-Value | p-Value | % of Change |
|------------|----|-----------|-------|-------|------|---------|---------|-------------|
| HDL        | 15 | Pre test  | 54.60 | 8.50  | 2.19 | 9.93    | .000    | 11%         |
|            |    | Post test | 60.53 | 10.22 | 2.64 |         |         |             |
| LDL        | 15 | Pre test  | 65.53 | 21.97 | 5.67 | 3.19    | .006    | 11%         |
|            |    | Post test | 57.80 | 17.73 | 4.57 |         |         |             |
| VLDL       | 15 | Pre test  | 16.20 | 4.57  | 4.57 | 6.34    | .000    | 15%         |
|            |    | Post test | 13.73 | 4.16  | 1.19 |         |         |             |

benefits of exercise training. The training program led to significant increases in levels of high-density lipoprotein cholesterol (HDL-C) and the ratio of HDL-C to low-density lipoprotein cholesterol (LDL-C) (HDL-C/LDL-C) (Cho et al., 2023). Additionally, plasma cholesterol (C), LDL-C, and triglyceride (TG) concentrations decreased following the exercise regimen. These beneficial changes in lipoprotein levels were attributed to the training program, as they were strongly correlated with improvements in the participants' maximum oxygen consumption ( $VO_{2max}$ ), which indicates improved cardiovascular fitness.

Furthermore, the positive effects of moderate-intensity endurance activity on lipoprotein profiles were observed not only in healthy individuals but also in patients with conditions such as ischemic heart disease, diabetes, and renal failure. The study demonstrated that endurance exercise training, performed at moderate to high intensities and regular frequencies, leads to favorable changes in plasma lipoproteins, particularly an increase in HDL-C levels and improvements in the HDL-C/LDL-C ratio. These findings highlight the importance of incorporating regular endurance exercise in promoting cardiovascular health in both healthy individuals and those with certain medical conditions. Meanwhile, the statistical findings of present study implies that the SAQ and Circuit training program of 12 weeks has significantly improved the HDL level from pre to post training in football players. It shows a significant trend in the changing pattern of HDL over football players. It indicates that regular exercise has positive influence on lipid profiles, including HDL levels. Training such as SAQ and circuit training, are particularly effective in raising HDL levels. These types of exercises involve continuous movement, increased heart rate, and prolonged energy expenditure, which can improve cholesterol metabolism and increase HDL production. The significant improvement in HDL levels observed in the study suggests that the 12-week SAQ and Circuit training program had a positive impact on cardiovascular health of soccer players. The specific combination of exercises, intensity, and duration likely contributed to the observed results. However, it's important to recognize that individual responses to exercise-induced changes in HDL levels may vary. Factors such as sample size, genetics, baseline fitness, dietary habits, and other lifestyle factors can influence how individuals respond to training interventions. It would be valuable to replicate the study with a larger sample size, control group, and longer follow-up to assess the long-term sustainability of the HDL improvement. According to (Rosenkilde et al., 2018) reported that the changes occur in HDL and lipid plasma are higher in men after considerably exposed in physical training. It has been suggested that relationship between the changes occur after the exercise might be of triglycerides metabolism. Free fatty acids are the major energy source during prolong endurance activity and HDL is intimately involved in fat metabolism (Farooque, Mitra, et al., 2023). This exercise induces and changes in the lipo-protein might be because of the adaptation to replenish intra-muscular free fatty acids used during exercises. Even the present study shows a greater effect of Circuit training (which purposively construct endurance form of activity) on HDL concentration when compare to SAQ training (Speed, Agility and Quickness). According to Despres JP 1991 regular endurance exercise

is extensively documented on modality to raise plasma HDL cholesterol levels. In support of the current study, (Sarzynski et al., 2022) reported that HDL cholesterol concentrations have been shown to increase with regular endurance exercise and, thus, can contribute to a lower risk of coronary heart disease in physically active individuals compared to sedentary subjects. In addition, (Ruiz-Ramie et al., 2019) reported from two different studies that individual with high cholesterol level before training increase more when compare to low training group. Some authors even claims that the weight loss associated with exercise training produces the increase in HDL cholesterol (Gordon et al., 2014b). The positive changes in HDL after training has been reported softly by different authors. No studies have been found which defined the actual mechanism of HDL in improving performance. However, it has been reported that HDL accept the excess surface of fatty particles after catabolism of fat for energy production removed through HDL path flow. The higher concentration of HDL in plasma could constrained LDL oxidation which keeps individual safe and sound from getting into heart related risk diseases.

These inconsistent findings suggest that the effects of an endurance training program on TC, TG, LDL-C, and TC/HDL-C may be affected by the length of the training time or other uncontrollable factors. Lin et al. (2015) found that athletes with elevated pre-exercise LDL concentrations responded most favorably to exercise training in a meta-analysis of multiple longitudinal trials. The present study reveals a decrease in the LDL concentration level when compare to pre and post of 12 weeks SAQ and circuit training on soccer players. Both the SAQ and Circuit group has shown significant reduction in LDL concentration level. From the result we can see the certain positive effect on LDL concentration and reduce the risk of sudden cardiac related attack. On the contrary, Previous research revealed that the free and esterified cholesterol of low density lipoprotein show a significant diurnal variation and it was suggested that dietary intake plays major and crucial role in increasing and lowering of the concentration level of LDL (Beunders et al., 2020). A limitation of this study is that dietary intake and nutritional status of the player was not under control as it has given the different variation in the concentration level of LDL in our body. Further, relevant studies in LDL have carried out by different authors which shown ultimate reduction in the concentration of LDL because of the triglyceride's metabolism carried out in the body. A meta-analysis of 170,000 participants were carried out (Navarese et al., 2018), and it suggested that reductions in LDL cholesterol decreased the occurrence of heart attacks and ischemic strokes. Physical activity and different from of training are directly related with reduction of LDL which is very important to sustain for prevention of cardiac diseases. Swiftly, higher intake of oxygen during the training lead to oxidative stress which may be remunerated by higher levels of free radicals scavengers of low molecular mass and by the higher activities of antioxidant enzymes.

VLDL excretion percentage reduced significantly throughout the exercise and persisted on repressing during recovery. Total VLDL-TG oxidation proportion was natural by exercise. However, the contribution of VLDL-TG oxidation to total energy expenditure fell from  $14 \pm 9\%$  at rest to  $3 \pm 4\%$  during exercise (Sondergaard et al., 2011).

Further suggested that lesser VLDL exudation degree during exercise may contribute to the decrease in TG concentrations during and after exercise. VLDL-TG fatty acids, on the other hand, are quantitatively significant oxidative substrates under basal post absorptive settings but are unaltered over 90 minutes of moderate-intensity exercise and so become relatively less important during exercise (Sondergaard et al., 2011). Significant reduction in the level of VLDL has been observed in the present study. The pre training results pertained to the VLDL was  $20.33 \pm 15.86$  which reduced to  $15.86 \pm 6.34$  after 12 weeks SAQ training. In case of circuit training significant decrease in the concentration level of VLDL was observed, pre- ( $16.20 \pm 4.57$ ) and post- ( $13.73 \pm 4.16$ ) which is comparatively better than SAQ training. Eventually the effect occurs after the training rely over the different forms of training. Endurance forms of training has certainly impact over the changes of lipoprotein. Here in this study the subject was neither sedentary nor inactive people. All the subjects were elite level players who have improve and develop a certain level of fitness. Even though some exceptional players are still existing which have higher concentration of VLDL in the study.

## Conclusion

In the light of the findings the study concludes that the intervention of endurance and speed-based training program improves the concentration of HDL, LDL and VLDL of elite soccer players. The training program led to an increase in the concentration of high-density lipoprotein (HDL) cholesterol. The training program also resulted in a decrease in the concentrations of low-density lipoprotein (LDL) and very-low-density lipoprotein (VLDL) cholesterol. Similarly, elevated levels of VLDL are associated with an increased risk of cardiovascular issues. The decrease in these cholesterol fractions is beneficial for overall cardiovascular health. The study suggests that for elite soccer players to observe significant improvements in their lipid metabolism, the training program should be prolonged, lasting at least more than 8 weeks. This indicates that long-term, consistent training is necessary to achieve substantial changes in cholesterol levels and lipid profiles. The conclusion implies that an appropriately designed endurance and speed-based training program can have substantial benefits on the lipid metabolism of elite soccer players. By increasing HDL levels and reducing LDL and VLDL levels, the program contributes to improved cardiovascular health and lowers the risk of heart-related issues. However, it's important to note that individual responses to the training may vary, and factors such as diet, genetics, and lifestyle also play significant roles in influencing lipid metabolism. Therefore, a holistic approach that includes both exercise and healthy dietary habits is crucial for optimizing the lipid profile and overall health of elite soccer players.

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## Conflict of interest

The authors declare no conflict of interest.

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# ВПЛИВ ТРЕНУВАНЬ НА ШВИДКІСТЬ, СПРИТНІСТЬ І МОТОРНІСТЬ ТА КОЛОВИХ ТРЕНУВАНЬ НА ВМІСТ ЛІПІДІВ У КРОВІ ФУТБОЛІСТІВ: СПОСТЕРЕЖНЕ ДОСЛІДЖЕННЯ

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

Реферат. Стаття: 7 с., 2 таб., 29 джерел.

**Мета дослідження.** Метою цього спостережного дослідження було вивчення впливу програми тренувань на швидкість, спритність і моторність (ШСМ) і кругових тренувань на вміст ліпідів у крові футболістів. Увагу в дослідженні зосереджено на аналізі змін концентрацій холестерину ліпопротеїнів високої щільності (ЛПВЩ), ліпопротеїнів низької щільності (ЛПНЩ) і ліпопротеїнів дуже низької щільності (ЛПДНЩ) після втручання.

**Матеріали та методи.** У дослідженні взяли участь 30 елітних футболістів із середнім показником (Sd, середнє квадратичне відхилення) віку 16,93 (1,20) року; зросту 5,66 (0,16) фута; ваги 59,93 (5,47) кг. Усі гравці, відібрані для дослідження, були зареєстрованими гравцями Академії Полоі, Імпхал, Маніпур (Індія). Учасників розподілили на дві групи, тобто групу тренувань на ШСМ і групу колових тренувань, і вони пройшли 12-тижневу програму тренувань на ШСМ і колових тренувань відповідно, яку проводили 3 дні на тиждень. Для вимірювання рівнів холестерину ЛПВЩ, ЛПНЩ та ЛПДНЩ збирали зразки крові до та після втручання. Вміст ліпідів у крові учасників оцінювали за допомогою стандартних лабораторних методів.

**Результати.** Результати цього дослідження продемонстрували статистично значущі зміни у вмісті ліпідів у крові елітних футболістів після проходження програми тренувань на ШСМ і колових тренувань. Втручання призвело до статистично значущого підвищення рівня холестерину ЛПВЩ. Водночас спостерігалось суттєве зниження концентрації холестерину ЛПНЩ та ЛПДНЩ.

**Висновки.** Підвищення рівня холестерину ЛПВЩ і зниження рівня холестерину ЛПНЩ і ЛПДНЩ вказують на потенційне зниження ризику серцево-судинних захворювань і пов'язаних із ними проблем зі здоров'ям. Беручи до уваги важливість ліпідного обміну для спортивних показників і загального самопочуття, це дослідження забезпечує цінні аналітичні дані для тренерів, спортсменів і спортивних професіоналів у розробці цільових режимів тренувань для оптимізації здоров'я серцево-судинної системи футболістів. Проте для підтвердження валідності та узагальнення цих одержаних результатів для різних контингентів і спортивних дисциплін потрібні подальші дослідження з більшими розмірами вибірки та тривалими наступними спостереженнями.

**Ключові слова:** ЛПВЩ, ЛПНЩ, ЛПДНЩ, тренування на ШСМ, холестерин, колове тренування.

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## THE EFFECTS OF LTAD-BASED PROGRAMMING ON FUNDAMENTAL SKILLS AND PHYSICAL ABILITIES OF BASKETBALL PLAYERS AGED 11-12 YEARS

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### Abstract

**Study purpose.** The purpose of this research is to determine the effect of LTAD-based programming on the physical abilities and fundamental skills of basketball players aged 11-12 years.

**Materials and methods.** The research method used was an experimental one-group pretest-posttest design. The study participants included 50 basketball players, 25 males and 25 females, weighing  $\pm 50-70$  kg and standing 159-172 cm tall. The instruments used consisted of a multistage fitness test, 30-meter sprint, Illinois run, layup, shooting under the ring, and free throw. Data was gathered by observation and testing. The data was analyzed descriptively using Wilcoxon and Mann-Whitney tests, which were aided by SPSS version 23.

**Results.** The results of the male and female groups' pretest-posttest showed that the Asymp.sig (2-tailed) values for the aspects of endurance, speed, agility, layup, shooting under the ring, and free throw were  $0.000 < 0.05$ . The results of the posttest comparison between males and females revealed that the Asymp.sig (2-tailed) value for the aspects of endurance, agility, speed, layup, and free throw was  $0.264-0.938 > 0.05$ , only for shooting under the ring the Asymp.sig (2-tailed) value was  $0.008 < 0.05$ .

**Conclusions.** The male and female groups' posttest results were better than the pretest results before LTAD-based programming. The majority of the posttest comparisons between males and females revealed no significant differences. This suggests that both the male and female groups improved after receiving LTAD-based programming.

**Keywords:** long-term athlete development, LTAD-based programming, learn to train, basketball players aged 11-12 years.

### Introduction

Basketball sport development is inextricably linked to internal as well as external factors (Fox et al., 2017). Internal factors include motivation, self-confidence, and adequate human resources, while external factors such as good training programs, and the availability of complete infrastructure (Bompa O. Tudor, 2019). This is one of the most important aspects of basketball coaching development. One of the goals of basketball coaching is to assist athletes in reaching their peak performance at the specified age (Johnson et al., 2011). As a result, the concept of long-term athlete development is critical when managing training based on the athlete's chronological age.

The concept of long-term athlete development (LTAD) provides a method and philosophy for developing athletes as well as cultural changes in sports to produce game assessments and organized training program design (Siwik et al., 2015). Balyi coined the term "long-term athlete development", which consists of several stages that must be completed in a systematic order, including the active star, fundamental, learning to train, training to train, learning to complete, training to complete, learning to win, training to win, and active for life (Abdelrasoul, 2015; Balyi et al., 2013). The learning-to-train stage, which occurs between the ages of 8 and 12 years for both boys and females, is a critical mass for determining the best training arrangements (Abdelrasoul, 2015).

As a result, as a coach, he must learn how to develop abilities that are directed by long-term athlete development principles (Yudhistira, 2023). Athletes can actively participate in fun physical exercises such as developing

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flexibility, coordination, speed, endurance, and strength using their body weight or infrastructure such as medicine balls and so on during the learn-to-train stage (Abdelrasoul, 2015). Therefore, the primary focus at this stage is on developing fundamental techniques and physical abilities by chronological age (van Kooten, 2016). However, various issues arise while attempting to execute this concept.

A classic problem, for example, is that athletes are focused on achieving victory at a young age where the most important factor is success at a young age and placing specialization-oriented training programs to reach peak performance before a specified age (Yildirim et al., 2019). This contradicts the premise of long-term athlete development. Aside from that, the needs analysis in the form of observations and interviews with trainers revealed that they were already aware of the importance of teaching essential skills effectively and correctly. However, the use of the training model still does not reflect the LTAD idea, such as the application of the fundamental skills in the training model, which lacks variation and does not recognize the necessity of intervals and recuperation in a single training session. Intervals and recovery are part of the training in this case (Hausswirth & Mujika, 2013).

Besides, stretching is not particularly programmed and does not follow the rules for raising, activation, mobility, and potentiation (Jeffreys, 2018). According to research, flexibility is an essential component of excellent physical growth (Jeffreys, 2018). Training in the learning-to-train stage is conceptually engaging games-based training (Harrison et al., 2015). Aside from that, methods of training must be capable of including the development of cooperation, discipline, and process focus (Sulistiyono et al., 2022).

The authors examined numerous long-term athlete development concepts. Long-term athlete development conceptual model (Granacher et al., 2016), implementation of long-term athlete development from a trainer's perspective (Beaudoin et al., 2015), problems with adapting the long-term athlete development model from a social control perspective (Dowling et al., 2020), and youth athlete development model (Varghese et al., 2022). Sulistiyono et al. recently evaluated a training model focused on long-term athlete development, with the findings indicating an improvement in the physical ability aspect of soccer (Sulistiyono, Sugiyanto, et al., 2021).

The preceding research focuses solely on training conceptual models, narrative studies, exploration, adoption, and implementation from the trainer's and societal perspectives. The referenced study did not include basketball players aged 11 to 12. Empirical evidence on the use of the training model using the LTAD method for 11-12-year-olds in basketball has gotten less attention. According to past studies, there is still a scarcity of evidence-based research on the effectiveness of LTAD (Beaudoin et al., 2015; Ropret & Jevtić, 2019). In this regard, the author's purpose is to fill a vacuum in prior research by developing essential skills and physical capacities in basketball players aged 11-12 years using an LTAD-based training model.

The purpose of this study is to determine the effect that LTAD-based training programming has on physical abilities and fundamental skills in basketball players aged 11-12 years. The authors hypothesize that there is a considerable difference between the male pretest and posttest, and the female pretest and posttest. Furthermore, the authors

hypothesize that there is no significant difference in posttest findings between the male and female groups in terms of growth in physical abilities and fundamental skills in basketball players aged 11-12 years.

## Materials and methods

### Study participants

This is field-testing experimental research with a one-group pretest-posttest-posttest design (Yulianto & Yudhistira, 2021). This study compared the male group's pretest and posttest, as well as the female group's pretest and posttest. Following that, this study compares the male group's posttest to the female group's posttest. Participants included 50 basketball players, 25 males and 25 females, weighing 50-70 kilograms and standing 159-172 centimeters tall. All participants were given a pretest to observe initial results utilizing physical ability instruments such as aerobic endurance, speed, and agility tests, while fundamental skills were assessed using the dribble layup, under-the-ring, and free throw instruments. After determining the pretest findings for the male and female groups, they received treatment with LTAD-based programming developed by the authors. Four trainers assisted with the research to ensure its smooth operation.

### Study organization

Participants were given treatment in the form of LTAD-based programming prepared by the authors by adapting guidelines from relevant books, ebooks, and journal articles. Before any programming is given to athletes, it is validated by 5 experts, three of whom are nationally licensed basketball coaches and two of whom are lecturers who are knowledgeable about training programming. Based on this assessment, the program received a consensus with an average content validity result of 8.00-1.00, indicating that the program has good content validity (Pradipta et al., 2023; Yudhistira & Tomoliyus, 2020). As a result, the program can be utilized to treat basketball players aged 11 to 12. The minimum attendance of participants to take part in treatment is 80%. The multistage fitness test, 30-meter run, and Illinois agility run are among the test instruments used to assess physical ability (Wiriawan, 2017). The core skills were next tested, which include the dribble layup, under-the-ring, and free throw tests (Akinci & Kirazci, 2020; Marta, 2022; Mascaret et al., 2016).

The training program is delivered three to four times per week for a total of 24 meetings. With programmed training dose settings, one training session lasts roughly 120 minutes. The procedure for carrying out training for basketball players is guided by stretching using the raise, activation, mobility, and potential (RAMP) guidelines. After that, the core training one is started, which includes physical ability training such as agility and coordination, as well as speed, and then goes on to core training two, which includes instruction in fundamental skills such as passing, dribbling, and shooting. After that, proprioceptive neuromuscular facilitation (PNF) is used to provide cooling stretching. The preceding explanation is an example of this programming, which is, of course, tailored to specific training adaptations.

Two essential exercises, such as fundamental skills training and physical strength training, can be performed in a single training session. Aside from that, you can exercise physical talents such as agility and coordination training, speed and strength, or fundamental skills training such as shooting, dribbling passes, and offensive and defensive drill games in a single training session. To clarify, the LTAD-based training program is shown in Table 1 as follows:

### Statistical analysis

For this research, descriptive analysis was utilized to give maximum, minimum, mean, and standard deviation values (Dameria et al., 2023). In the second stage, the authors used the nonparametric Wilcoxon test to process the pretest and post-test data (Akhiruyanto et al., 2022), while the nonparametric Mann-Whitney test to compare post-test results for males and females (Pramono et al., 2023).

**Table 1.** LTAD-based training program for basketball players aged 11-12 years

| Warm-up program (RAMP)                 |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                    |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| No                                     | Practice Material                                                                                                                                                                                                                                                                                                                               | Dose                                                                                                                                                                                               |
| 1                                      | Raise: Leg high knee, Leg high knee right & left, Leg high knee 2x2<br><br>Activation & mobility: Shoulder rotation, sway squat, lunges, single leg knee flexion with internal rotation, single leg knee, plank with arm and leg raise.<br><br>Potentiation: wall ball drill, circle basketball around the waist, circle basketball around legs | Intensity: moderate<br>Volume (rep): 2-3-4x etc<br>Recovery: 2-3'<br><br>Intensity: low-moderate<br>Volume (reps): 8-10x<br><br>Intensity: low-moderate<br>Volume (sets x rep): 2-3-4 etc x 20-30" |
| Fundamental Skills Training Program    |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                    |
| 2a                                     | Passing: chest pass, bounce pass, overhead pass, baseball pass, one-handed chest pass, one-handed bounce pass                                                                                                                                                                                                                                   | Intensity: moderate<br>Volume (sets x rep): 2-3-4 etc x 10-15-20 etc<br>Recovery: 60"                                                                                                              |
| 2b                                     | Dribble: forward, backward, lateral, crossover                                                                                                                                                                                                                                                                                                  | Intensity: moderate<br>Volume (set x rep) 2-3-4 etc x 5-6-7 etc<br>Recovery: 60"                                                                                                                   |
| 2c                                     | Shooting: under basket, set shoot, lay up, free throw                                                                                                                                                                                                                                                                                           | Intensity: moderate<br>Volume (sets x rep): 2-3-4 etc x 10-12-15 etc<br>Recovery: 60"                                                                                                              |
| Game Practice Program                  |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                    |
| 3a                                     | Defense drill: Defense shuffle, mirror drill                                                                                                                                                                                                                                                                                                    | Intensity: maximum<br>Duration: 10-15-20'                                                                                                                                                          |
| 3b                                     | Offensive drill: box out drill, one on one drill                                                                                                                                                                                                                                                                                                | Intensity: maximum<br>Duration: 10-15-20'                                                                                                                                                          |
| 3a                                     | Another drill: pick a setting, inbounding the ball                                                                                                                                                                                                                                                                                              | Intensity: maximum<br>Duration: 10-15-20'                                                                                                                                                          |
| Physical Ability Training Program      |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                    |
| 4a                                     | Agility balance, coordination: ladder rabbit hops, straddle hops squat, hopscotch, ladder taps right and left, ladder single leg hops right and left                                                                                                                                                                                            | Intensity: low-moderate<br>Volume (sets x rep): 6-8 x 3-4-5 etc<br>Intervals: 10-15"<br>Recovery: 60"                                                                                              |
| 4b                                     | Speed: Forward sprint, backpedal sprint, lateral sprint                                                                                                                                                                                                                                                                                         | Intensity: maximum<br>Distance: 30-40 meters<br>Rep: 2-3-4 etc<br>Recovery: 40-60-90                                                                                                               |
| 4c                                     | Strength: goblet squat, split squat, box jump, scapula push-up, band overhead press, standing band row, overhead squat, renegade row, situp                                                                                                                                                                                                     | Intensity: low-moderate<br>Volume (sets x rep): 2-3-4 etc x 6-8-9-10<br>Recovery: 2-3'<br>Media: 1kg barbell, light-medium size resistance band                                                    |
| Cooling down exercise program with PNF |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                    |
| 5                                      | Hamstring and glute stretch, chest stretch, shoulder stretch, tricep stretch, quadriceps stretch                                                                                                                                                                                                                                                | Rep: 2-3-4 etc<br>Count: 1-6" per move<br>Count: 7-10" counter per move                                                                                                                            |

**Table 2.** Results of descriptive analysis of physical abilities and fundamental skills of basketball players aged 11-12 years

| Group  | Variable            | Pretest |       |        |         | Posttest |       |       |         |
|--------|---------------------|---------|-------|--------|---------|----------|-------|-------|---------|
|        |                     | Min     | Max   | Mean   | SD      | Min      | Mac   | Mean  | SD      |
| Male   | Durability          | 27.02   | 43.06 | 33.94  | 4.94431 | 32.09    | 45.08 | 36.97 | 3.45426 |
|        | Speed               | 4.98    | 6.50  | 5.64   | 0.32225 | 4.10     | 5.90  | 4.945 | 0.33786 |
|        | Agility             | 18.24   | 22.45 | 19.87  | 0.93851 | 17.00    | 21.01 | 18.96 | 1.03899 |
|        | Right dribble layup | 1       | 6     | 3      | 1.519   | 4        | 7     | 5     | 0.963   |
|        | Dribble lay up left | 0       | 5     | 2      | 1.700   | 4        | 7     | 5     | 0.831   |
|        | Under ring          | 6       | 26    | 17     | 5.100   | 11       | 28    | 20    | 4.698   |
|        | Freethrow           | 1       | 10    | 6      | 2.548   | 6        | 16    | 10    | 2.712   |
| Female | Durability          | 27.02   | 43.06 | 33.94  | 4.94431 | 32.09    | 45.08 | 36.97 | 3.45426 |
|        | Speed               | 4.98    | 6.50  | 5.6472 | 0.32225 | 41.10    | 5.90  | 4.945 | 0.33786 |
|        | Agility             | 18.24   | 22.45 | 19.87  | 0.93851 | 17.00    | 21.01 | 18.96 | 1.03899 |
|        | Right dribble layup | 1       | 7     | 2      | 1.498   | 4        | 8     | 5     | 0.843   |
|        | Dribble lay up left | 1       | 5     | 2      | 1.150   | 4        | 7     | 4     | 0.862   |
|        | Under ring          | 7       | 24    | 12     | 5.297   | 9        | 26    | 16    | 4.830   |
|        | Freethrow           | 1       | 11    | 5      | 2.609   | 6        | 15    | 9     | 2.147   |

This data processing was assisted by the SPSS version 23 application. To make it clearer, we have presented the results of the descriptive analysis in Table 2 as follows.

## Results

Wilcoxon analysis of the Asymp.sig (2-tailed) value of the male group regarding physical abilities which include endurance, speed, and overall agility produces a value of  $0.000 < 0.05$ , while the fundamental aspects of skill which include right and left dribble layup, under ring, and free throw, overall produces a value of  $0.000 < 0.05$ . This shows that there is a significant difference between the male group's pretest and posttest. According to the findings above, there was a significant improvement in physical abilities and fundamental skills when compared to the male group's pretest and posttest scores. The Wilcoxon analysis of the Asymp.sig (2-tailed) value of the female group's physical abilities such as endurance, speed, and overall agility produced a value of  $0.000-0.001 < 0.05$ , whereas fundamental skills such as right and left dribble layup, under the ring, and free throw yielded a value of  $0.000 < 0.05$ . These findings reveal that there is a substantial difference between the male group's pretest and posttest. According to the findings above, there was substantial improvement in physical abilities and fundamental skills when compared to the female group's pretest and posttest scores.

The Mann-Whitney analysis with Asymp.sig (2-tailed) values for the physical ability variable yielded the following results: endurance  $0.662 > 0.05$ , speed  $0.938 > 0.05$ , and agility  $0.727 > 0.05$ . This suggests that there is no substantial difference in physical abilities between the male and female groups, although the average scores for the male and female groups tend to be the same. There is only one significant difference in the overall fundamental skill results, and that is shooting under the ring  $0.008 < 0.05$ . As a result, the male and female groups differ significantly. Aside from the under-ring variable, no significant differences were found between male

**Table 3.** Comparison results of pretest and posttest for male and female groups based on Wilcoxon analysis

| Group  | Variable                       | Asymp. sig (2-tailed) |
|--------|--------------------------------|-----------------------|
| Male   | Pretest – endurance            | 0.000                 |
|        | Posttest – endurance           |                       |
|        | Pretest – speed                | 0.000                 |
|        | Posttest – speed               |                       |
|        | Pretest – agility              | 0.000                 |
|        | Posttest – agility             |                       |
|        | Pretest – right dribble layup  | 0.000                 |
|        | Posttest – right dribble layup |                       |
|        | Pretest – left dribble layup   | 0.000                 |
|        | Posttest – left dribble layup  |                       |
|        | Pretest – under the ring       | 0.000                 |
|        | Posttest – under ring          |                       |
| Female | Pretest – free throw           | 0.000                 |
|        | Posttest – free throw          |                       |
|        | Pretest – endurance            | 0.001                 |
|        | Posttest – endurance           |                       |
|        | Pretest – speed                | 0.000                 |
|        | Posttest – speed               |                       |
|        | Pretest – agility              | 0.000                 |
|        | Posttest – agility             |                       |
|        | Pretest – right dribble layup  | 0.000                 |
|        | Posttest – right dribble layup |                       |
|        | Pretest – left dribble layup   | 0.000                 |
|        | Posttest – left dribble layup  |                       |
|        | Pretest – under the ring       | 0.000                 |
|        | Posttest – under ring          |                       |
|        | Pretest – free throw           | 0.000                 |
|        | Posttest – free throw          |                       |

**Table 4.** Posttest comparison results for male and female groups based on Mann-Whitney analysis

| Group  | Variable            | Mean value | Asymp. sig (2-tailed) |
|--------|---------------------|------------|-----------------------|
| Male   | Endurance           | 36.97      | 0.662                 |
| Female |                     | 36.97      |                       |
| Male   | Speed               | 4.945      | 0.938                 |
| Female |                     | 4.945      |                       |
| Male   | Agility             | 18.96      | 0.727                 |
| Female |                     | 18.96      |                       |
| Male   | Right dribble layup | 5          | 0.264                 |
| Female |                     | 5          |                       |
| Male   | Left dribble layup  | 5          | 0.163                 |
| Female |                     | 4          |                       |
| Male   | Under ring          | 20         | 0.008                 |
| Female |                     | 16         |                       |
| Male   | Freethrow           | 10         | 0.198                 |
| Female |                     | 9          |                       |

and female groups. According to the mean value, the male group outperforms the female group. To make it clearer, the mean value is presented using the diagram in Figure 1 as follows:

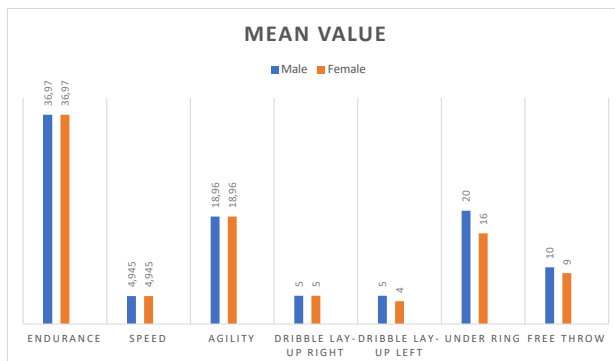


**Fig. 1.** Diagram of the average posttest score for the male and female groups

## Discussion

The purpose of this study is to determine how long-term athlete development (LTAD)-based programming affects physical abilities such as aerobic endurance, speed, and agility, as well as fundamental skills, including dribble layups, shooting under the ring, and shooting free throws in basketball players aged 11-12 years. The authors observed a difference between pretest and posttest in the male group and between pretest and posttest in the female group. The posttest findings from the male and female groups were then compared.

The results of the Wilcoxon analysis, Asymp.sig (2-tailed) values in the pretest and posttest of the male group for the physical ability variable produced the following results: endurance  $0.000 < 0.05$ , speed  $0.000 < 0.05$ , agility  $0.000 < 0.05$ , while the fundamental skill variable includes right dribble lay

up  $0.000 < 0.05$ , left dribble lay up  $0.000 < 0.05$ , shooting under the ring  $0.000 < 0.05$ , and shooting free throw  $0.000 < 0.05$ . This indicates that there is a significant difference between the pretest and posttest in the male group. These findings reveal that long-term athlete development (LTAD)-based programming resulted in a considerable increase in pretest and posttest physical ability.

Wilcoxon analysis of Asymp.sig (2-tailed) values for the pretest and posttest of the female group for the physical ability variable gave the following results: endurance  $0.001 < 0.05$ , speed  $0.000 < 0.05$ , agility  $0.000 < 0.05$ , while fundamental skill variables include right dribble lay up  $0.000 < 0.05$ , left dribble lay up  $0.000 < 0.05$ , shooting under the ring  $0.000 < 0.05$ , and shooting free throw  $0.000 < 0.05$ . This indicates that there is a significant difference between the pretest and posttest in the female group. These findings reveal that long-term athlete development (LTAD)-based programming resulted in a considerable increase in pretest and posttest physical ability.

The Mann-Whitney analysis of Asymp.sig (2-tailed) values for the physical ability variable yielded the following results: endurance  $0.662 > 0.05$ , speed  $0.938 > 0.05$ , and agility  $0.727 > 0.05$ . As a result, there is no significant difference in physical abilities between male and female groups. They tend to be the same based on the mean values of the male and female groups. Right dribble layup  $0.264 > 0.05$ , left dribble layup  $0.163 > 0.05$ , shooting beneath the ring  $0.008 > 0.05$ , and free throw shooting  $0.198 > 0.05$  are fundamental skill variables. There is only one significant difference between the male and female groups in the fundamental skill findings, which is shooting under the ring of  $0.008 < 0.05$ . Aside from the shooting under ring variable, there were no significant changes between male and female groups following treatment.

The authors' findings are consistent with Granacher et al.'s study, which states that physical ability training related to muscle endurance is important during the long-term athlete development stage to stimulate athlete development, tolerate the demands of long-term training and competition, and minimize the effects of injury in the future (Granacher et al., 2016). Coaches must specifically facilitate exercises related to body balance, and weight training with a focus on movement technique, complex exercises, and plyometric exercises that are appropriate to the training dose during the long-term development stage of athletes to provide benefits in athletic performance and muscle fitness (Granacher et al., 2016).

Recently, ladder-based plyometrics training programming for 11-12-year-olds was created using proper training guidelines to produce increased physical abilities such as agility, leg muscle power, and aerobic endurance (Pramono et al., 2023). Recent data on the impact of long-term athlete development-based training on physical abilities and academic accomplishment was also discovered; the results significantly improved physical abilities such as leg muscle power, aerobic endurance, and 30-meter sprint in soccer players aged 11-12 years (Sulistiyo, Sugiyanto, et al., 2021). Physical abilities must be specifically developed to support motor skills, improve health, and reduce injuries (Faigenbaum et al., 2016; Loyd et al., 2015). Furthermore, improving physical ability can promote athletes' long-term career development (Loyd et al., 2015).

The findings of the authors suggest that LTAD-based programming improves fundamental skills in basketball

players aged 11 to 12. This is consistent with previous research in the sport of soccer for players aged 10 to 12 years old using a games experience learning training model based on the LTAD programming concept (Sulistiyono, Akhiruyanto, et al., 2021). Treatment carried out for 10 weeks with a training frequency of 3 times a week was able to provide improvements in basic soccer playing techniques compared to conventional methods that had been applied (Sulistiyono, Akhiruyanto, et al., 2021). Likewise, Yudanto et al.'s research applied the games experience learning model with LTAD principles compared to the technical approach method with the results of the experience of the game learning training model being better than the technical approach in improving football playing skills (Yudanto, Suherman, et al., 2022; Yudanto, Yudhistira, et al., 2022). Wicaksono et al.'s research also applies the part and whole method, this method has the principle of LTAD programming at the learning-to-train stage (Wicaksono & Hidayatullah, 2022). As a result, this method can improve basic skills in the sport of volleyball (Wicaksono & Hidayatullah, 2022).

Furthermore, the authors compared the male and female groups' post-test outcomes in terms of physical ability and essential competencies. The results for the male and female groups did not differ significantly, and the results for numerous components could even be considered identical. At the learn-to-train stage, LTAD-based programming delivers equivalent progress for males and females, with programming properly monitored from the treatment process, rest patterns, and adequate nutrition. According to developmental psychology, when children between the ages of 6 and 12 attend elementary school, their growth will accelerate, as will their development of movement and nerves (Firdaus, 2012). Aside from that, male athletes' growth tends to slow down at the age of 8, whilst female athletes' growth accelerates (Jahja, 2011). As a result, as a coach, you must understand the athlete's growth and development to properly alter the programming (Hadi et al., 2022).

Gender sexual maturity undoubtedly differs (Jahja, 2011). Children are eager to study, understand knowledge, and have a high level of curiosity throughout this period (Jahja, 2011). As a result, the trainer takes on crucial roles such as administrator, facilitator, motivator, and well-managed training program (Saifu et al., 2021; Wicaksono & Hidayatullah, 2022). Equally crucial factors are parental support and the surrounding environment because even if the athlete is brilliant if parental and environmental support is lacking, the desired results will be thwarted (Harris et al., 2014; Martens, 2012; Rodis, 2013). Experts agree that at this age, assistance from family, peers, and school influences social development to attain success in sporting achievements (Dorsch et al., 2021).

In the sport of basketball, the learn-to-train stage is a perfect moment for optimizing physical skills and abilities (O'Sullivan, 2014). According to studies, this stage is a semi-specific development that must be directed (Styasih et al., 2016). Furthermore, this stage is critical for improving movement speed and coordination (Ivashchenko et al., 2018). Coordination is defined as the coordination of body and brain motions to carry out certain movements (Hadi & Yudhistira, 2023). This stage is an accelerated period for improving fundamental basketball skills and physical abilities (Guimarães et al., 2019). This can be regarded as

an athlete's thirst for knowledge, hence the involvement of parents and coaches is critical in guiding athletes (Haddad et al., 2021). As a result, it becomes a severe issue when the trainer is unfamiliar with the details of this level.

Long-term athlete development provides a solution to these challenges (Ford et al., 2011). This concept is relevant from both internal and external perspectives (Ford et al., 2011). Similarly, several studies support the authors' findings that the LTAD concept provides a structured and systematic pathway to optimize development from gifted children to elite athletes by taking individual maturity into account based on chronological age (Balyi et al., 2013; Dowling et al., 2020; Ford et al., 2011).

This concept will run smoothly when there is synergy between coaches, organizational management, and supportive parents (Dowling et al., 2020). This concept is quite complex since it discusses not only how athletes might excel now, but also philosophical development in terms of cognitive, affective, and psychomotor development (Styasih et al., 2016). The concept outlines stages that must be completed based on the athlete's chronological age (Balyi, 2004).

The concept of LTAD is inextricably linked to the science of sports pedagogy. Sports pedagogy is related to how someone helps children and young people explore their potential through sport (Armour, 2013). The point is about how children learn in every aspect of education both at school and outside of school (Armour, 2013). According to another study, sports pedagogy is a guide and procedure for learning sports-specific abilities (Lee et al., 2014). Aside from that, the most significant aspect is how this learning may be implemented effectively so that athletes can get individual, social, and health benefits (Armour, 2013).

## Conclusion

According to the findings and discussion, providing treatment with LTAD-based programming at the learning-to-train stage can improve physical abilities such as endurance, speed, and agility, as well as fundamental skills, including shooting, shooting under the ring, and free throw shooting in both male and female groups. The comparison of the male and female posttests did not appear to cause significant differences, implying that the male and female groups given LTAD-based programming achieved the same good results. As a result, LTAD programming is a concept that is required in the field of performance sports, particularly basketball, to enhance long-term performance based on an athlete's physiological and chronological age. However, future studies will necessitate a more in-depth discussion, such as implementing longitudinal-based interventions to acquire more comprehensive findings.

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## Conflict of interest

All authors declare no conflict of interest.

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## ВПЛИВ ПРОГРАМУВАННЯ НА БАЗІ МОДЕЛІ LTAD НА ФУНДАМЕНТАЛЬНІ НАВИЧКИ ТА ФІЗИЧНІ ЗДІБНОСТІ БАСКЕТБОЛІСТІВ ВІКОМ 11-12 РОКІВ

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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., 1 рис., 54 джерел.

**Мета дослідження.** Метою цього дослідження є визначення впливу програмування на базі моделі Довгострокового розвитку спортсменів (LTAD) на фізичні здібності та фундаментальні навички баскетболістів віком 11-12 років.

**Матеріали та методи.** Як метод дослідження використовували експериментальний план із попереднім і підсумковим тестуванням на одній групі. Учасниками дослідження були 50 баскетболістів, 25 чоловічої статі та 25 жіночої статі, вагою  $\pm 50-70$  кг і зростом 159-172 см. Інструменти, які використовували, включали багатоетапний тест на функціональний стан, біг на 30 метрів, Іллінойський тест на біг, кидок однією рукою з-під кільця з відскоком м'яча від щита, кидок однією рукою з-під кільця без відскоку м'яча від щита і штрафний кидок. Дані збирали шляхом спостереження та тестування. Дані аналізували описово з використанням критеріїв Вілкоксона та Манна-Уїтні за допомогою програмного забезпечення SPSS версії 23.

**Результати.** Результати попереднього та підсумкового тестування чоловічої та жіночої груп показали, що значення асимптотичної значущості (2-сторонньої) для аспектів витривалості, швидкості, спритності, кидка однією рукою з-під кільця з відскоком м'яча від щита, кидка однією рукою з-під кільця без відскоку м'яча від щита та штрафного кидка становили  $0,000 < 0,05$ . Результати порівняння показників підсумкового тестування між чоловічою та жіночою групами показали, що значення асимптотичної значущості (2-сторонньої) для аспектів витривалості, спритності, швидкості, кидка однією рукою з-під кільця з відскоком м'яча від щита та штрафного кидка становило  $0,264-0,938 > 0,05$ , і лише для кидка однією рукою з-під кільця без відскоку м'яча від щита значення асимптотичної значущості (2-сторонньої) становило  $0,008 < 0,05$ .

**Висновки.** Результати підсумкового тестування чоловічої та жіночої груп були кращими за результати попереднього тестування до програмування на базі моделі Довгострокового розвитку спортсменів (LTAD). У більшості порівнянь результатів підсумкового тестування між чоловічою та жіночою групами не було виявлено статистично значущих відмінностей. Це дає підстави вважати, що і чоловіча, і жіноча групи покращили свої результати після застосування до них програмування на базі моделі Довгострокового розвитку спортсменів (LTAD).

**Ключові слова:** довгостроковий розвиток спортсменів, програмування на базі моделі Довгострокового розвитку спортсменів (LTAD), вчитися тренувати, бакетболісти віком 11-12 років.

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ORIGINAL SCIENTIFIC ARTICLE

## BIOMECHANICAL MOTION OF THE TENNIS FOREHAND STROKE: ANALYZING THE IMPACT ON THE BALL SPEED USING BIOFOR ANALYSIS SOFTWARE

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### Abstract

**Background.** The inefficiency of the forehand stroke technique often stems from suboptimal execution of an athlete's biomechanical movements. For a forehand stroke to be effective, each biomechanical component – the ankles, knees, hips, shoulders, and elbows – must function in an optimal manner. Disconnection of any of these elements can lead to ineffective technique. High speed, influenced by the racket speed at the point of impact, is a key indicator of a perfect forehand stroke. However, the challenge lies in the fact that an athlete's movement and ball impact cannot be accurately observed with the naked eye, necessitating specialized tools for analysis.

**Study purpose.** The study aims to develop software that assists in predicting ball speed outcomes based on an athlete's biomechanical movement during a forehand stroke execution.

**Materials and methods.** The research method employed R&D. Data collection techniques consisted of video recordings of athletes' forehand strokes, which were later analyzed using software that examines movement angles of 10 national athletes.

**Results.** The results indicated the average angles of elbows = 106.23, shoulders = 153.62, hips = 165.33, knees = 167.63, ankles = 164.54; and ball speed = 199.41 cm/s.

**Conclusions.** The conclusion drawn is that to execute an effective forehand stroke with good ball speed, a moment of inertia must occur at the point of impact. The athletes should bend their elbow slightly, thereby reducing rotational resistance and increasing the speed of the racket head. The ankles, hips, and shoulders must move in synchronization within a continuous coordination chain, thereby allowing the athlete to fully leverage kinetic chain. The flexion movement of the elbow during the forward swing step is more effective than the extension movement where the elbow is slightly bent, resulting in a perfect shot.

**Keywords:** biomechanics, software, forehand, tennis.

### Introduction

Tennis encompasses a variety of techniques such as the forehand, backhand, volley, smash, and service. Among these, the forehand stroke remains the most prevalently used by tennis players (İbrahim et al., 2013; Keaney & Reid, 2018). Advanced players utilize the forehand stroke technique approximately 85% of the time in every match (Martin-Lorente et al., 2017). This technique is the most

natural, simplest to learn, and most frequently deployed in tennis (Brown & Soulier, 2013).

In competitive tennis, it is widely acknowledged that points are often secured or conceded based on a powerful and consistent forehand groundstroke (Kwon et al., 2017). An analysis of point acquisition among elite tennis players highlighted that more points were won with the forehand than the backhand (Genevois et al., 2015); in competitive settings, forehand strokes are employed 25% more frequently than backhand strokes (Nangia et al., 2021).

The forehand stroke can be broken down into three stages: preparation, acceleration, and follow-through. The preparation stage encompasses the backswing movement

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up to the forward swing. The acceleration stage starts from the forward swing until impact. The follow-through stage is marked by the racket's impact and subsequent follow-through (Rigozzi et al., 2023). In this study, the impact phase, where the ball and racket collide to generate ball speed, is used as a variable for product research.

One frequent issue observed on the court is an ineffective forehand stroke technique, which limits the power of the forehand stroke. This is often attributed to coaches' limited understanding of biomechanics. Without the ability to accurately analyze techniques, athletes struggle to enhance their performance, risking potential injuries that could hinder their achievements. Unresolved incorrect movements become ingrained through repetitive training, complicating technical progression and potentially leading to musculoskeletal joint damage (Gao et al., 2019).

Work biomechanics focuses on mechanical processes such as force, speed, acceleration, momentum, and pressure within the human body, in relation to the physical activities performed by athletes (Sari et al., 2017). The biomechanical foundation for executing a forehand stroke is vital for optimal performance and injury prevention (Elliott et al., 2018). The primary aim of applying work biomechanics is to enhance human movement performance and mitigate the risk of injury to the human musculoskeletal system (Iridiastadi et al., 2014).

The biomechanical movement of the forehand stroke technique is crucial in executing a dynamic stroke with speed, necessitating consistent and strong muscle contraction training. Functional tennis should incorporate dynamic strength training, rather than static training. This involves controlling, stabilizing, and slowing the body using eccentric contractions, while concentric contractions generate rapid body movements. For instance, to recover the forehand stroke movement after a series of movements, eccentric contraction occurs in the thigh muscles when the foot lands and will recover again when preparing for a forehand stroke. To execute a perfect forehand stroke with effective and efficient biomechanical movement, concentric contraction is performed in front of the shoulder when swinging as swiftly as possible.

Analyzing biomechanical movement is not feasible through observation alone; it necessitates the utilization of technology. Past research (Evita & Subagio, 2020) conducted an analysis of biomechanical movement using Kinovea software, assessing arm and leg angles during the initial, preparation, backswing, forward swing, and follow-through phases. In another study (Sari et al., 2017), a body movement measurement instrument was developed using a sensor medium named ESMOCA, which measures angles and calculates biomechanics. This study employed two models for biomechanical measurements: the hand-elbow model and the lower back model. The hand-elbow model focused on measurements of the palm, forearm, and upper arm, while the lower back model focused on measurements of the upper and lower back. Research by (Bakhtiar et al., 2020) developed a system that could estimate the impact force on the forehand stroke by embedding signals into the racket.

In this context, the researcher developed a software tool called "Biofor Analysis Software". This tool functions by recording the athlete's forehand stroke movement on video, which is then imported into the software. The software

automatically analyzes and detects the athlete's movement upon ball-racket impact. At the moment of impact, the software reads the body segment angle of biomechanical movement, including the ankle, knees, hips, shoulders, elbow, and ball speed. Thus, by understanding the angle of movement at the time of ball impact, it becomes possible to predict the resulting ball speed.

In research (Evita & Subagio, 2020), the biomechanical movement analysis using Kinovea required users to manually analyze the athlete's movement angle. The analyzed movement angles were limited to the leg and hand angles, and there was no measurement for the resulting ball speed. In contrast, the research conducted by the current researcher includes a comprehensive analysis of body segments such as the ankles, knees, hips, shoulders, elbows, and also measures the ball speed.

The research (Sari et al., 2017) utilized a sensor medium named ESMOCA, attaching sensors to both the leg and arm angles. However, attaching sensors to the legs and body can restrict the athlete's movement, and the sensors can easily detach and are expensive. In contrast, the current research measures the body segment angles of the ankles, knees, hips, shoulders, and elbows without using sensor media, making the process simpler, more practical, and cost-effective.

Research (Bakhtiar et al., 2020) used a single variable of impact force to determine ball speed by attaching a signal to the racket, which is less straightforward and requires additional hardware, and it does not cover the aspect of biomechanics that the current research aims to develop. The current research is more practical and straightforward as it does not require hardware, can directly detect ball speed through ball collision (impact), and can detect biomechanical movement through body segments such as the ankles, knees, hips, shoulders, and elbows. The study aims to develop software that assists in predicting ball speed outcomes based on an athlete's biomechanical movement during a forehand strike impact.

## Materials and methods

### Study participants

The research methodology adopted in this study is Research & Development, incorporating both qualitative and quantitative data. The study's population comprises 10 athletes from Pre-PON Jateng, consisting of five male and five female athletes, and 10 Unnes tennis UKM athletes, again with an equal gender distribution. The sample is saturated with all the population members serving as sample members, and the criteria for selection are male athletes, resulting in a total sample of 10 athletes.

### Study organization

The research design is experimental and data collection techniques include questionnaires for experts to assess the validity of the instrument. The sample was tested three times. The test instrument uses a ball launcher and a video camcorder/android phone. The product developed in this study is the Biofor Motion Analysis Software application, designed to predict forehand stroke speed based on the angle of biomechanical movement at the point of ball impact.

The product observes the biomechanical movement from the ankles, knees, hips, shoulders, and elbows at the moment of ball impact. The system can automatically calculate the angle. The system operates by collecting image data of the tennis player using an Internet of Things (IoT) Modbus sensor image acquisition circuit (Peng & Tang, 2022). The product will detect the player's movement angle using the principle of human pose detection, which has 32 detection points on the human body, and detect ball speed. The results of detecting the player's movement angle and ball speed are stored in Excel as the final result of this product.

The stages of the research development procedure include: 1) product analysis, 2) initial software instrument and product development, 3) expert judgment, 4) product trials, and 5) product revision.

The implementation of the research began with the component analysis stage. This tool product will produce output in the form of ball speed data and the pose of players during the game. The required input data are spatial data in RGB format where the player and ball are present. The main components used are listed below.

#### Software



##### Python 3

A programming language used to detect objects in the form of humans and tennis balls.



Visual Studio Code

##### Visual Studio Code

An application for editing programming languages.



##### Iriun

A tool to connect the webcam to the PC using a wifi network.

#### Hardware



##### Webcam

Used to record in real time at a predetermined court angle.



##### Tripod

A supporting tool for the webcam during video shooting.



##### Meter

A tool to measure the angle of video shooting or the size of the field.

The product will detect the player's movement angle using the principle of human pose detection, which has 32 detection points on the human body, and detect ball speed. The results of detecting the player's movement angle and ball speed are stored in Excel as the final result of this product. The flow diagram of how the system works:

#### Statistical analysis

This study uses descriptive and inferential analysis with Two-Way ANOVA classification using the formula:

$$F = (R_{Ka}/R_{Kd}) > F_{k-1; n-k} \text{ or Sig. (P\_value)}$$

Where:

$$JK_a = nS \bar{X}^2 - (\sum x^2/k)$$

$$JK_d = JK_{smk}$$

$$JK_T = JK_a + JK_d$$

$$df \text{ } JK_a = k-1$$

$$df \text{ } JK_d = N-k$$

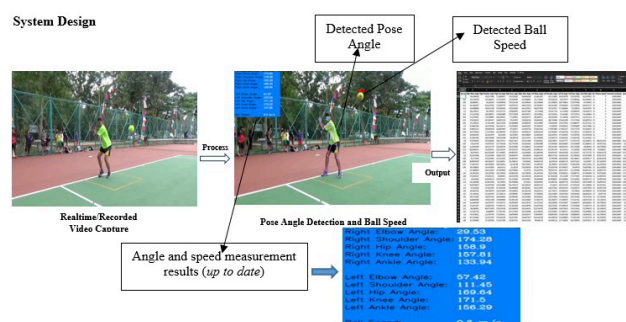


Fig. 1. Workflow System

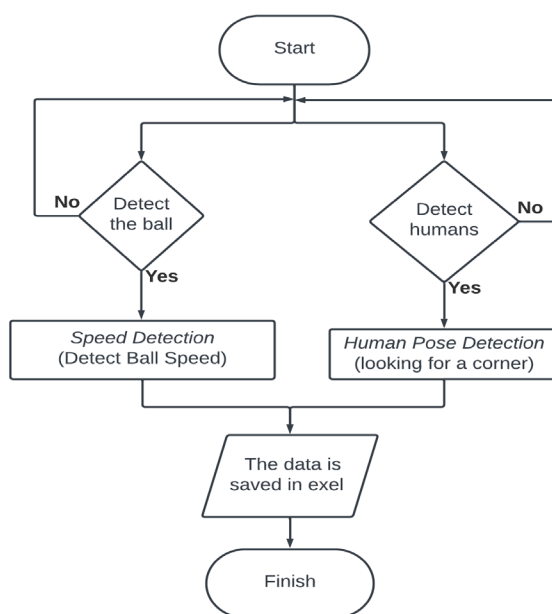


Fig. 2. How Product System Works

To ensure accuracy, the SPSS version 25 program is used. The sample used in the research trial is illustrated in Figure 1, which presents the system product work.

#### Results

The research on forehand stroke technique using a ball launcher was conducted at the Dr. Sajoto tennis court, FIK, Unnes from 14 July to 14 October 2023. The results of the biomechanical movement test of the forehand stroke are as follows.

From Table 1, at the moment of ball impact, the average angles were – ankles: 164.54, knees: 167.63, hips: 165.33, shoulders: 153.62, elbows: 106.23, and ball speed: 199.41 with a standard deviation of 42.41. The data show that the software can accurately read the angles of biomechanical movement and ball speed. Each stroke is analyzed by the system up to 206 frames. The researcher only needs to determine the optimal point position when the ball impact occurs and then analyze each movement based on the appropriate movement mechanics.

**Table 1.** Average ball impact of athletes' forehand stroke

| No.     | Player's | Result |           |        |        |        |            |
|---------|----------|--------|-----------|--------|--------|--------|------------|
|         |          | Elbows | Shoulders | Hips   | Knees  | Legs   | Ball Speed |
| 1       | A-1-1    | 59.02  | 149.88    | 163.78 | 147.89 | 140.73 | 266.4      |
|         | A-1-2    | 67.19  | 175.56    | 160.01 | 169.47 | 152.44 | 176.8      |
|         | A-1-3    | 71.34  | 165.23    | 162.34 | 152.84 | 154.96 | 258.8      |
| 2       | A-2-1    | 85.99  | 137.61    | 160.32 | 177.87 | 177.63 | 268.4      |
|         | A-2-2    | 98.35  | 156.29    | 166.5  | 169.55 | 159.25 | 157.7      |
|         | A-2-3    | 133.08 | 135.6     | 167.26 | 168.17 | 157.65 | 133.7      |
| 3       | A-3-1    | 96.47  | 126.33    | 172.19 | 159.95 | 156.76 | 155.4      |
|         | A-3-2    | 82.62  | 133.79    | 172.17 | 173.38 | 171.89 | 291.3      |
|         | A-3-3    | 77.59  | 123.77    | 176.67 | 160.9  | 159.11 | 182.8      |
| 4       | A-4-1    | 176.49 | 173.55    | 165.75 | 177.52 | 172.45 | 129.7      |
|         | A-4-2    | 177.56 | 173.9     | 159.0  | 177.57 | 172.42 | 127.7      |
|         | A-4-3    | 149.84 | 158.08    | 160.81 | 174.61 | 173.78 | 239.2      |
| 5       | A-5-1    | 156.44 | 160.95    | 161.48 | 165.97 | 159.18 | 92.6       |
|         | A-5-2    | 88.25  | 178.73    | 165.72 | 178.12 | 175.76 | 147.3      |
|         | A-5-3    | 126.47 | 122.04    | 165.62 | 162.85 | 151.77 | 91.8       |
| 6       | A-6-1    | 146.67 | 141.13    | 163.82 | 169.29 | 168.79 | 112.6      |
|         | A-6-2    | 121.10 | 154.2     | 162.88 | 172.68 | 162.80 | 134.4      |
|         | A-6-3    | 129.53 | 149.33    | 161.14 | 175.95 | 164.78 | 131.1      |
| 7       | A-7-1    | 75     | 142.49    | 163.53 | 175.18 | 174.18 | 120.9      |
|         | A-7-2    | 73.62  | 156.27    | 175.52 | 166.17 | 159.96 | 162.6      |
|         | A-7-3    | 88.75  | 133.17    | 168.25 | 166.69 | 179.98 | 117.1      |
| 8       | A-8-1    | 58.68  | 148.71    | 170.41 | 156.71 | 163.23 | 262        |
|         | A-8-2    | 69.95  | 117.91    | 175.5  | 165.37 | 158.98 | 169.8      |
|         | A-8-3    | 107.21 | 132.44    | 169.09 | 170.03 | 161.17 | 140.9      |
| 9       | A-9-1    | 152.58 | 168.01    | 166.09 | 168.42 | 164.75 | 345.9      |
|         | A-9-2    | 170.44 | 179.87    | 156.73 | 177.89 | 178.62 | 165.6      |
|         | A-9-3    | 159.55 | 164.71    | 162.48 | 174.7  | 177.8  | 394.2      |
| 10      | A-10-1   | 70.25  | 159.65    | 159.25 | 154.24 | 157.86 | 359.8      |
|         | A-10-2   | 55.26  | 172.9     | 163.9  | 178.44 | 162.63 | 361.2      |
|         | A-10-3   | 61.43  | 163.95    | 163.64 | 155.57 | 162.58 | 246.2      |
| Average |          | 106.23 | 153.62    | 165.33 | 167.63 | 164.54 | 199.41     |
| SD      |          | 42.41  |           |        |        |        |            |

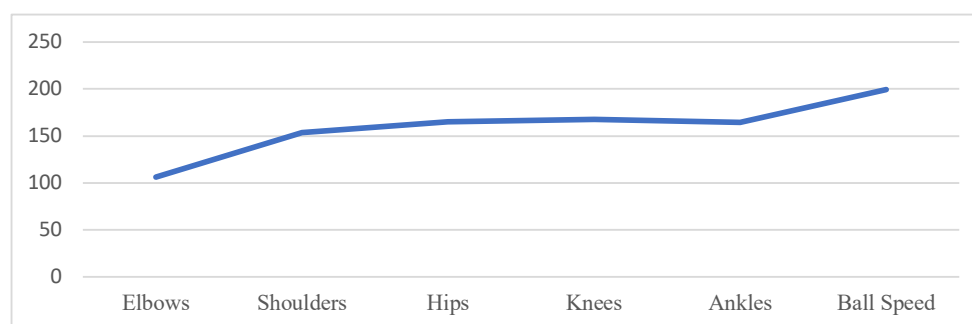


**Fig. 3.** Average Biomechanics of Forehand Stroke Impact

## Discussion

A well-executed racket strike is when the racket head trails the handle, allowing the player to utilize the ball's momentum for added power upon impact. The ball's effect on the racket at the point of impact assists the player in

generating additional power and control. The racket plays a crucial role upon impact. The racket experiences an impact force from the ball, causing vibrations and generating a unique frequency. Sunku Kwon (Kwon et al., 2017) suggested that the angle of the racket head (open/closed) affects ball speed. Tom Allen (Allen et al., 2011) argued that alterations

**Table 2.** Biomechanical Movement at the Moment of Impact

| Body Part            | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shoulder             | <p><b>Body work:</b> the head has to keep in line with the shoulders to keep balanced. The shoulders guide the arm movement.</p> <p><b>Biomechanical consequences:</b> Head and shoulders co-operate to keep balance throughout the impact.</p> <p><b>Practical points:</b> Teach your players to “watch” the ball at impact and to keep the chin up and forward.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Trunk and upper body | <p><b>Body work:</b> Correct use of all body parts,. Grip: the further the grip is towards “western” the sharper the arc of the racket path at contact point. Grip tension: is required to counteract any “off-centre” impact which create torque, good timing.</p> <p><b>Biomechanical consequences:</b> By correct use of the body’s co-ordination chain, racket head speed is generated, as angular momentum is transferred through the heavy parts of the body (which are the moving slowly) (eg. Torso) to the light parts (wrist) ( which therefore have to move very fast), to keep the formula of weight x speed balanced. The western grips create topspin through applying torque on the ball. The torque is a product of the ball’s momentum at impact and how far off the centre of the racket the impact occurred. By controlling the co-ordination chain and its constituent units, and interpreting the ball’s flight path.</p> <p><b>Practical points:</b> Remember that extreme grips have disadvantages associated with shot variety and shot improvisation. Ball hit from the “sweet-spot” require very little tension. Grip tension during the take-back and swing is counter-productive. Helping the player to hit with rhythm or flow is essential when searching for racket head speed. Help the player to hit the ball well rather than just trying to hit hard.</p> |
| Hips                 | <p><b>Body work:</b> They keep in line with the shoulders.</p> <p><b>Biomechanical consequences:</b> Hips, trunk and shoulders are the basic elements to maintain the balance throughout the impact.</p> <p><b>Practical points:</b> Teach your players that during impact (0.004 secs) balance is extremely important.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

to the racket head influence the racket’s operating system. A closed racket head angle results in a higher ball speed compared to an open racket head angle (Ikenaga et al., 2020), and the speed of the racket head influences ball speed upon forehand stroke impact (Elliott et al., 2018).

At the moment of racket and ball impact, the shoulders swing forcefully to generate explosive power. According to (Reid et al., 2013) and (Genevois et al., 2015), in terms of kinematics, skilled players apply more body rotation during the execution of the forehand stroke, resulting in a higher shoulder speed.

The results from the study (Iino, 2018) demonstrate that the rotational speed of the hips on the player’s side is positively related to the horizontal racket speed at the moment of impact.

The movement of the back foot following impact influences the ball speed (Shimokawa et al., 2022). The more forward the back foot moves after impact, the greater the power generated. In biomechanics, this is referred to as linear momentum, which involves moving body weight forward towards the stroke.

The legs, hips, and trunk should move in a synchronized chain of coordination, enabling athletes to fully harness the kinetic chain (Roetert et al., 2009).

The flexion movement of the elbow during the forward swing phase is more effective than the extension movement of the elbow (Widiyatmoko et al., 2021). Keeping the elbow slightly bent leads to a perfect shot and minimizes the risk of injuries.

Cyril Genevois (Genevois et al., 2020) stated that the internal rotation of the humerus and pronation of the lower arm contribute to an ideal shot. This action should occur naturally without forcing the wrist into extension; it should happen as a result of stroke mechanics and good power preparation. Most professional players achieve a degree of delay before making contact with the ball. With a semi-western grip at impact, certain outcomes are produced (Bahamonde, 2001), including:

- Due to the semi-western grip, the wrist is pulled back at impact.
- The head remains entirely still, and the eyes focus on the stroke.
- Typically, an open-stance foot positioning is observed at the time of impact. Research has shown that top players (both men and women) use an open-stance on the forehand 90% of the time.
- Knee extension, along with right hip rotation, ensures the load is transferred along the racket head’s path from the swing before and after collision.
- The racket head may be slightly below the wrist at impact, which can be acceptable.
- If the racket head is significantly below the wrist, then the grip will weaken and control will decrease.

The advantage of the product developed in this research is its ease and practicality of use for measuring biomechanical movement and ball speed, and its cost-effectiveness. However, the product also has a limitation: the forehand speed in the program is still measured in pixels/second in the 2D space of the video image, and not in actual measurements. Therefore, it needs to be adjusted to the dimensions of the field size and the athlete’s forehand speed reference.

There were several challenges encountered during data collection, including the need for a sterile field free from surrounding objects such as scattered leaves, rolling balls during the athlete test, and clothing that must not be similar in color to the ball. Despite these challenges, the strength of this research is that the data collection process is straightforward because it only relies on a video camcorder or Android phone.

## Conclusions

The analysis of the biomechanical motion of a forehand stroke, specifically in relation to ball speed, can be evaluated through the observed impact of the ball and the corresponding angles of the ankles, knees, hips, shoulders, and elbows. The

findings of this study confirm that the developed product can precisely detect the angular movements of athletes and the corresponding ball speed. It is thus inferred that this tool is apt for athletes and trainers to scrutinize and appraise forehand stroke techniques, resulting in the optimization and enhancement of biomechanical movements. It is advisable for coaches to utilize this tool to augment the forehand technique and amplify the power of their athletes' forehand strokes. In the event of movement discrepancies, the software is proficient in identifying the precise location of these errors, thus enabling coaches to implement corrective strategies in subsequent training sessions.

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## Conflict of interest

All author have declared no conflict of interest.

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# БІОМЕХАНІЧНИЙ РУХ ТЕНІСНОГО УДАРУ ВІДКРИТОЮ РАКЕТКОЮ: АНАЛІЗ ВПЛИВУ НА ШВИДКІСТЬ М'ЯЧА ЗА ДОПОМОГОЮ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ BIOFOR ANALYSIS

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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., 3 рис., 24 джерела.

**Історія питання.** Неефективність техніки удару відкритою ракеткою часто пов'язана з неоптимальним виконанням біомеханічних рухів спортсменом. Для того, щоб удар відкритою ракеткою був ефективним, кожен біомеханічний компонент – щиколотки, коліна, стегна, плечі та лікті – повинен функціонувати оптимальним чином. Відключення будь-якого із цих елементів може призвести до неефективності техніки. Висока швидкість, яка залежить від швидкості ракетки в точці удару, є ключовим показником ідеального удару відкритою ракеткою. Проте проблема полягає в тому, що рух спортсмена та удар по м'ячу неможливо точно спостерігати неозброєним оком, тому для аналізу потрібні спеціальні інструменти.

**Мета дослідження.** Метою дослідження є розробка програмного забезпечення, яке допомагає прогнозувати результати швидкості м'яча залежно від біомеханічного руху спортсмена під час виконання удару відкритою ракеткою.

**Матеріали та методи.** Метод дослідження передбачав застосування НДДКР. Методи збору даних включали відео-записи ударів спортсменів відкритою ракеткою, які пізніше аналізували за допомогою програмного забезпечення, яке аналізує кути рухів 10 національних спортсменів.

**Результати.** Результати показали середні кути ліктів = 106,23, плечей = 153,62, стегон = 165,33, колін = 167,63, щиколоток = 164,54; і швидкість м'яча = 199,41 см/с.

**Висновки.** Зроблений висновок полягає в тому, що для виконання ефективного удару відкритою ракеткою з гарною швидкістю м'яча в точці удару має виникнути момент інерції. Спортсменам слід трохи згинати лікоть, тим самим зменшуючи опір обертанню та збільшуючи швидкість голови ракетки. Щиколотки, стегна та плечі повинні рухатися синхронно в межах безперервного координаційного ланцюга, тим самим дозволяючи спортсмену повністю й максимально ефективно використовувати кінетичний ланцюг. Рух згинання ліктя під час виконання маху вперед є ефективнішим, ніж рух розгинання, коли лікоть трохи зігнутий, що дає в результаті ідеальний удар.

**Ключові слова:** біомеханіка, програмне забезпечення, удар відкритою ракеткою, теніс.

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## SOMATOTYPES OF EAST-ZONE INDIAN INTER-UNIVERSITY KHO-KHO PLAYERS

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### Abstract

**Background.** Somatotyping in modern sports can be an important factor to be considered. Different studies have already taken the initial step to identify the sport-specific somatotypes for different games and sports. In contrast with the Kho-Kho game, some attempts have been made to identify somatotypes specific for these games. But there are only few studies that have been conducted, and various areas are still waiting to be explored.

**Study purpose.** The present study aimed to identify the specific somatotypes of the kho-kho players. Additionally, this study also made an attempt to explore the important somatic traits that influence the somatotypes of the Kho-Kho players.

**Materials and methods.** A total number of 74 players from six Kho-Kho teams that participated in East Zone Inter-University Tournament were purposively selected for the study. The anthropometric data collection was done according to the standard procedures given by ISAK (International Society for Advancement of Kinanthropometry). The statistical analysis was done by using MS Excel (2021) and SPSS'23.

**Results.** The results of the study showed that most of the Kho-Kho players (90.6%) were possessing ectomorphic and mesomorphic dominant traits. There was also a significant difference found in ectomorphic and mesomorphic traits among the players possessing mesomorphic-ectomorph ( $p < 0.05$ ), ectomorphic-mesomorph ( $p < 0.05$ ) and ectomorph-mesomorph ( $p < 0.05$ ) somatotypes. Furthermore, the discriminant analysis also highlighted that attributes of ectomorphic traits (Discriminant coefficient = 1.168) and mesomorphic traits (Discriminant coefficient = 0.812) were important somatic traits for the Kho-Kho players. Overall, 88.6% of the original cases have been correctly represented by the discriminant analysis.

**Conclusions.** The present study showed that Kho-Kho players for the most part possess the ectomorphic and mesomorphic dominant somatotypes. Furthermore, based on the study results, it can be also concluded that somatic attributes in the similar body types also play important role to determine players' performance level.

**Keywords:** anthropometric, ectomorph, mesomorph, endomorph, discriminant analysis.

### Introduction

The impact of somatotypes on sport performance is a very important area to be study in the field of sport science (Eston & Reilly, 2009). Based on athlete's physical traits, including lean muscle mass and body fat distribution somatotype can be differentiated. This somatotypes are mainly endomorphic, mesomorphic, ectomorphic dominant types (Carter, 2002). Several studies (Ryan-Stewart, 2018; Cardenas-Fernandez, 2017; Kandel, 2014) showed that there is positive relation exists between the somatotyping and

sport performance. It was investigated that the mesomorph and ectomorph dominant traits might be the essential factor for strength specific games (Ryan-Stewart, 2018). Similarly, some games having some specific somatotypes has very much position impact on the game performance (Cárdenas-Fernández, 2017). Having low rate of endomorphic traits and higher ectomorphic dominant somatic traits can influence the agility related movements (Kandel, 2014). These forementioned studies indicates that there is a relationship exist in between sport and somatotypes. A number of studies has already established positive impact of somatotypes in relates to different games and sports. However, there are only a few studies found regarding the impact of somatotypes on the indigenous sport Kho-Kho.

The playing style of Kho-Kho is very highly intensive and dynamic in nature. It requires speed, ability to change the direction, endurance and explosive leg power as a basic physical abilities (Joshi & Kalode, 2019; Rathore & Singh, 2014). These specific physical abilities also related to the somatic traits of the athlete. Studies showed that mesomorph characteristics have very much correlation with the explosive power (Cinar and Koca, 2018). Ectomorph dominant somatotypes were suitable for the events that requires endurance and strength for prolonged time (Cinar & Koca, 2018; Franchini et al., 2019). The endomorphic somatotypes may not dominant in sporting event. Somehow it is also possessed by the athletes but less dominant while compared to other two dominants characteristics (Cinar and Koca, 2018). It is understandable that different body shapes may have distinct benefits or drawbacks in terms of in-game performance (Kandel et al., 2014; Knechlte et al., 2010; Giannopoulos et al., 2017). These potential relationships might also be better understood by looking at somatotype of kho-kho players.

Existed literature already explained the relation among physiological parameters and kho-kho playing abilities (Perumal et al., 2019; Pal et al., 2018). However, the importance of somatic traits and somatotype were not examined thoroughly in Kho-Kho games. Though they were very much related to physiological variables (Perumal et al., 2019; Pal et al., 2018; Kandel et al., 2014; Knechlte et al., 2010; Giannopoulos et al., 2017). Some Studies tried to investigate anthropometric measures and somatotypes with playing abilities (Manohar, 2015; Jaiswal, 2014). However, very limited number of studies has aimed to identify the distinct somatotypes of the kho-kho players.

Therefore, the present study firstly aimed to identify the the somatotypes of the kho-kho players. Secondly, this study also aimed to find out the which somatic traits were more distinctive. Analyzing across different somatotype categories of Kho-Kho players, specific somatic traits could be uncovered. Understanding the somatotypes of the kho-kho players with performance level will hold significant value for optimizing training programs, talent identification, and player development strategies within this unique. When the possible relationship between somatic features within the performance level is investigated, significant insights into the physical needs and potential advantages of certain body types can be established.

## Materials and methods

### Participants

All the players were selected from teams participated in East Zone Inter University Kho-Kho Tournament (India) held in the year 2023. The present study was confined among six (6) teams; among which three (3) of them were finalist and three (3) of them were non-finalist team. All the teams were purposively selected and they had played minimum 4 matches. The total number of 74 (34 from finalist team 40 from non-finalist team) players were from both finalist and non-finalist teams were participated.

### Data collection

A written consent from the respected teams were taken prior to the collection of the data. All anthropometric measurements were taken according to guidelines given

by ISAK (The International Society for Advancement of Kinanthropometry). The anthropometric measurements were measured by ISAK (level-1) certified person only. The Standards and tools for the assessment given by ISAK were used for the calculation of the somatic traits (Norton, K., 2018)

In the following table 1 description of the anthropometric dimensions has been mentioned.

**Table 1.** Description of sites for measure, equipment's used and unit of measure

| Sites for the measurements                                       | Equipments used                                    | Units of measure |
|------------------------------------------------------------------|----------------------------------------------------|------------------|
| Standing stature                                                 | Stadiometer (Seca 213)                             | Centimetre (cm)  |
| Body mass                                                        | Weighing machine (Hoffen Digital weighing machine) | Kilogram (kg)    |
| Four skinfolds (triceps, subscapular, supraspinale, medial calf) | Harpender calliper (Galaxy)                        | Millimetre (mm)  |
| Two bone breadths (bicipondylar humerus and femur)               | Sliding calliper (Cescorphy)                       | Centimetre (cm)  |
| Two limb girths (arm flexed and tensed, calf)                    | Anthropometric tape (Cescorphy)                    | Centimetre (cm)  |

### Classification of the participants

All the participants teams has been categorized into qualified and non-qualified groups based on the qualification criteria of the tournament. It was assumed that players of qualified teams were better at performer. In support, a Team Performance Index (SPI) was calculated to ranked the all qualified and non-qualified teams to observe the performance level. The SPI has been calculated based on ratio of point scored by a team per matches and matches played (minimum 4 matches).

### Team Performance Index (TPI):

Team performance Index (TPI) in constructed for the ranked the teams based on their overall team performance.

Mathematical expression for (TPI):

$$TPI = \frac{\sum(S_n / T_n)}{N};$$

Where  $S_n$  = Total Point scored in each match played ( $n=1, 2, 3, 4, \dots, n$ ).  $T_n$  = Time duration taken for score 'Sn'.

### Statistical analysis

All the collected data has analysed using MS Excel (2021) and SPSS'23. Descriptive statistics were implied as required to present the data. To determine the significance difference between the finalist team and non-finalist team 't-test' was applied at 0.05 significance level.

The discriminant analysis has been done for identification of the most influential somatic trait on the somatotypes of the kho-kho players. All the players were divided into two groups based on a criterion which was qualification for the final round and failed to qualify for the final round. The somatic traits which are ectomorph, mesomorphic and endomorph has been considered as independent variables. Based on these somatic traits, discriminant coefficient was calculated for the forementioned somatic traits from the both players of the categorial groups. The significance of the model has been further evaluated by analysing Wilk's Lambda value and the canonical correlation coefficient.

## Results

In this following section obtained result of the current study has been mentioned. The table 2 provides somatotype characteristics for non-qualified teams (N=40) and qualified teams (N=34) in a competition. The somatotypes are categorized based on endomorphic, mesomorphic and ectomorphic traits. The players from the qualified teams with mesomorphic-ectomorph players showed a mean score of  $1.64 \pm 0.52$ ,  $4.37 \pm 0.14$ , &  $5.32 \pm 0.16$  for endomorphic, mesomorphic, and ectomorphic traits, respectively (table 2).

And for the ectomorphic-mesomorph types the average scores for endomorphic, mesomorphic, and ectomorphic traits are  $1.67 \pm 0.31$ ,  $5.12 \pm 0.11$ , and  $4.30 \pm 0.18$ , respectively (table 2). The scores for endomorphic, mesomorphic, and ectomorphic traits are  $2.00 \pm 0.22$ ,  $4.00$ , and  $4.00$ , respectively for the mesomorph-ectomorph types (table 1). The mean score of the balanced-ectomorph for endomorphic, mesomorphic, and ectomorphic traits are  $2.5 \pm 0.11$ ,  $2.5 \pm 0.11$  &  $4.98 \pm 0.16$  respectively and for the body types balanced-mesomorph the mean scores are  $2.4 \pm 0.08$ ,  $5$ ,  $2.4 \pm 0.08$ . On the other hand, For the players of non-qualified teams having mesomorphic-ectomorph somatotype, showed average scores for endomorphic, mesomorphic, and ectomorphic traits are  $1.87 \pm 0.12$ ,  $3.03 \pm 0.65$ , and  $4.45 \pm 0.61$ , respectively (table 2). Similarly, players of non-qualified teams possessed by ectomorphic-mesomorph somatotypes, the average scores for endomorphic, mesomorphic, and ectomorphic traits are  $1.99 \pm 0.22$ ,  $4.20 \pm 0.54$ , and  $3.90 \pm 0.54$  respectively and for mesomorph-ectomorph, the scores for endomorphic, mesomorphic, and ectomorphic traits are  $2.00 \pm 0.11$ ,  $3.22$ , and  $3.22$ , respectively (table 2). The mean score of the balanced-ectomorph for endomorphic, mesomorphic, and ectomorphic traits are  $2$ ,  $2$  &  $4.36 \pm 0.08$  respectively and for

the body types balanced-mesomorph the mean scores are  $2.67 \pm 0.03$ ,  $4.87 \pm 0.03$ ,  $2.67 \pm 0.21$  (table 2).

**Table 3.** Overall description of the somatotypes among the EZIU Kho-Kho players, 2023

| SL No. | Somatotypes           | Distribution of the players (N=74) |       |
|--------|-----------------------|------------------------------------|-------|
| 1      | Mesomorphic-ectomorph | 36.5 %                             | 90.6% |
| 2      | Ectomorphic-mesomorph | 23.0%                              |       |
| 3      | Mesomorph-ectomorph   | 12.2%                              |       |
| 4      | Balanced-mesomorph    | 10.8%                              |       |
| 5      | Balanced-ectomorph    | 8.1%                               |       |
| 6      | Endomorphic mesomorph | 4.1%                               |       |
| 7      | Endomorphic-ectomorph | 2.7%                               |       |
| 8      | Endomorph-mesomorph   | 1.4%                               |       |
| 9      | Mesomorphic-endomorph | 1.4%                               |       |

The description of of the body types possessed by the kho-kho players from EZIU, 2023 were presented in table 3. It showed total number of nine (9) somatotypes were found among the players. From the table 3 it presented that mesomorphic-ectomorph (36.5%), ectomorphic mesomorph (23%) and mesomorph-ectomorph (12.2%) were at the top of the table 3. Whereas endomorphic dominant somatotypes were positioned at the bottom based on their percentage distribution.

Table 4 showed that rank of the teams based on the Team performance index. It can be observed from table 4, that qualified teams DD, TMB & PRV having TPI credit more than 1. (1.53, 1.36 & 1.19 respectively). While non-qualified teams NS, SMBP & BH having comparatively low TPI credit equal or less than 1 (1, 0.94 & 0.72 respectively).

Table 5 represented the difference of somatic traits between qualified and non-qualified teams. It showed that players with mesomorphic-ectomorph types having attributes of mesomorphic ( $p = 0.0002$ ) and ectomorphic traits (0.0495) significantly higher than non-qualified teams (table 5). In somatotypes of ectomorphic-mesomorph, also having mesomorphic ( $p=0.001$ ) and ectomorphic traits ( $p = 0.044$ ) significantly differ than non-qualified teams (table 5). Similarly in mesomorph-ectomorph somatotypes showed better mesomorphic and ectomorphic traits among the players from the qualified teams ( $p = 0.03$  &  $p = 0.03$  respectively).

**Table 2.** Description somatic traits of qualified and non-qualified teams of EZIU Kho-Kho tournament, 2023

| Somatotypes           | Qualified Team                      |                                     |                                     | Non-qualified Team                  |                                     |                                     |
|-----------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|                       | Endo-morphic traits (Mean $\pm$ SD) | Meso-morphic traits (Mean $\pm$ SD) | Ecto-morphic traits (Mean $\pm$ SD) | Endo-morphic traits (Mean $\pm$ SD) | Meso-morphic traits (Mean $\pm$ SD) | Ecto-morphic traits (Mean $\pm$ SD) |
| mesomorphic-ectomorph | $1.64 \pm 0.52$                     | $3.29 \pm 0.46$                     | $5.35 \pm 0.16$                     | $1.87 \pm 0.12$                     | $2.86 \pm 0.38$                     | $4.45 \pm 0.61$                     |
| ectomorphic-mesomorph | $1.67 \pm 0.31$                     | $5.14 \pm 0.55$                     | $3.71 \pm 0.75$                     | $1.99 \pm 0.22$                     | $4.16 \pm 0.28$                     | $2.87 \pm 0.49$                     |
| mesomorph-ectomorph   | $2.00 \pm 0.22$                     | $5.50 \pm 0.70$                     | $5.50 \pm 0.70$                     | $2.00 \pm 0.11$                     | $3.12 \pm 0.37$                     | $3.12 \pm 0.37$                     |
| Balanced-ectomorph    | $2.50 \pm 0.11$                     | $2.50 \pm 0.11$                     | $4.98 \pm 0.16$                     | $2.00 \pm 0.23$                     | $2.00 \pm 0.23$                     | $4.36 \pm 0.16$                     |
| Balanced-mesomorph    | $2.10 \pm 0.45$                     | $4.85 \pm 0.95$                     | $2.10 \pm 0.45$                     | $2.00 \pm 0.97$                     | $4.87 \pm 0.03$                     | $2.00 \pm 0.97$                     |

**Table 4.** Description of the topmost five somatotypes (which describe more than 90% of the players) among the teams with their Performance Index

|                           | Team Initials | Team Performance Index (TPI) | Rank | Mesomorphic ectomorph (%) | Ectomorphic- Mesomorph (%) | Mesomorph- Ectomorph (%) | Balanced- ectomorph (%) | Balanced- mesomorph (%) |
|---------------------------|---------------|------------------------------|------|---------------------------|----------------------------|--------------------------|-------------------------|-------------------------|
| Qualified Team (N=32)     | DD            | 1.53                         | 1    | 63.64                     | 9.09                       | 9.09                     | 9.09                    | 9.09                    |
|                           | TMB           | 1.36                         | 2    | 20                        | 20                         | 10                       | 10                      | 40                      |
|                           | PRV           | 1.19                         | 3    | 36.36                     | 45.45                      | 00                       | 00                      | 18.18                   |
| Non-qualified Team (N=32) | NS            | 1                            | 4    | 35.71                     | 28.57                      | 21.43                    | 7.14                    | 7.14                    |
|                           | SMBP          | 0.94                         | 5    | 33.33                     | 22.22                      | 33.33                    | 11.11                   | 0                       |
|                           | BH            | 0.72                         | 6    | 33.33                     | 33.33                      | 11.11                    | 00                      | 22.22                   |

However, among these three somatotypes endomorphic traits were having insignificant difference between the qualified and non-qualified teams ( $p=0.0181, 0.195$  &  $0.50$  respectively) (table 5).

The table 6 represents the results of a discriminant analysis performed on a set of predictor variables to classify observations into two groups - qualified teams and non-qualified teams. The table shows the standardized and unstandardized discriminant function coefficients for the

three predictor variables - Ectomorphic traits (1.168 & 1.284), Mesomorphic traits Endomorphic traits (0.029 & 0.057). It also shows the values of group centroids value 1.267 and -1.267 for the qualified and non-qualified teams respectively. The eigenvalue found in this study is 1.683a and Wilk's Lambda coefficient is 0.373. The canonical correlation coefficient also found 0.792. These values in the table 6 can be used to estimate the discriminant function, evaluate its significance, assess classification accuracy and interpret the results of the analysis.

**Table 5.** Difference between somatic traits found between qualified and non-qualified teams

| Somatotypes           | Somatic Traits | Qualified Team (Mean) | Non-Qualified team (Mean) | p- value |
|-----------------------|----------------|-----------------------|---------------------------|----------|
| Mesomorphic-ectomorph | Endomorph      | 1.64                  | 1.87                      | 0.181    |
|                       | Mesomorph      | 3.29                  | 2.86                      | 0.010*   |
|                       | Ectomorph      | 5.35                  | 4.45                      | 0.001*   |
| Ectomorphic-mesomorph | Endomorph      | 1.67                  | 1.99                      | 0.195    |
|                       | Mesomorph      | 5.14                  | 4.16                      | 0.000*   |
|                       | Ectomorph      | 3.71                  | 2.87                      | 0.012*   |
| Ectomorph-mesomorph   | Endomorph      | 2                     | 2                         | 0.50     |
|                       | Mesomorph      | 5.5                   | 3.14                      | 0.04*    |
|                       | Ectomorph      | 5.5                   | 3.14                      | 0.04*    |
| Balanced-ectomorph    | Endomorph      | 2.5                   | 2                         | 0.42     |
|                       | Mesomorph      | 2.5                   | 2                         | 0.42     |
|                       | Ectomorph      | 4.98                  | 4.36                      | 0.61     |
| Balanced-mesomorph    | Endomorph      | 2.1                   | 2                         | 0.57     |
|                       | Mesomorph      | 5                     | 4.87                      | 0.68     |
|                       | Ectomorph      | 2.1                   | 2                         | 0.57     |

## Discussion

The finding of the study revealed that majority of the Kho-Kho players having ectomorphic or mesomorphic dominant traits. It was found that somatotypes such as mesomorphic-ectomorph, ectomorphic-mesomorph and mesomorph-ectomorph were possessed by more than 70% of the players. However, discriminant analysis showed that mesomorphic and ectomorphic attributes are significantly higher among the qualifying team. This might be the reason behind the performance difference in qualifying teams than non-qualifying teams.

It's interesting to note that somatic traits can have an impact on athletic performance, particularly in games like Kho-Kho that require speed and explosive power. According to Kumar and Arumugam (2018), individuals with ectomorphic and mesomorphic dominant traits tend to perform better in these areas. The present study also found that players from qualified teams exhibited comparatively higher somatic attributes than that of the non-qualified team (Table 2). Similarly, this study also indicates that more than 90% of the Kho-Kho players were having either ectomorph

**Table 6.** Interpretive measure for Discriminant Function Coefficients between players of qualified and non-qualified teams

| Variables           | Standardized Discriminant Function Coefficients | Unstandardized Discriminant Function Coefficients | Values of Group Centroids |                      | Eigen value        | Wilk's Lambda Coefficient | Canonical correlation |
|---------------------|-------------------------------------------------|---------------------------------------------------|---------------------------|----------------------|--------------------|---------------------------|-----------------------|
|                     |                                                 |                                                   | Qualified teams           | Non-qualified teams  |                    |                           |                       |
| Ecto-morphic Traits | 1.168                                           | 1.284                                             |                           |                      |                    |                           |                       |
| Meso-morphic Traits | 0.812                                           | 0.792                                             | 1.267 <sup>ac</sup>       | -1.261 <sup>bc</sup> | 1.683 <sup>a</sup> | 0.373                     | 0.792                 |
| Endo-morphic Traits | 0.029                                           | 0.057                                             |                           |                      |                    |                           |                       |

<sup>a</sup> For the Qualified teams 86.4% of original grouped cases has been correctly classified.

<sup>b</sup> For non-qualified team 90.9% of the original ceases has been correctly qualified.

<sup>c</sup> Overall, 88.6 % of the original cases has been correctly qualified.

or mesomorph characteristics as dominant traits (Table 3). Indeed, those 90% of the players can solely explained by five somatotypes, namely mesomorphic-ectomorph, ectomorphic-mesomorph, mesomorph-ectomorph, balanced-mesomorph and balanced ectomorph. These traits may contribute to an individual's ability to change direction quickly and generate explosive power, making them well-suited for sports like Kho-Kho (Manohar, 2015).

Achieving the optimal level of performance in any sport is contingent upon several factors, encompassing physical attributes, psychological elements, and skill-related aspects. A significant number of studies has been already enlightened that somatotyping on the basis of anthropometric factors has the possible effect on the sport performance (Malousaris et al., 2008; Sleeper et al., 2012; Singh et al., 2010). Importantly, the utilization of a targeted training program also has the potential to induce transformations in anthropometric variables, consequently leading to notable alterations in somatic traits. An investigation conducted by Sadeghkhani et al. (2022), showed that planned plyometric and resistance training program can be effective on the attributes of ectomorphic and mesomorphic traits of athletes. The study was conducted for eight weeks on the elite sport person of various fields. The findings of the study demonstrated that this particular training program resulted in significant changes in somatic traits among the participants (Sadeghkhani et al., 2022). A number of studies (Sleeper et al., 2012; Zaccagni, 2012; Ostojic, 2006) has been also indicated that specific training regimens can have a direct or indirect influenced the somatotypes and somatic traits. This might be one of the reasons for which majority (more than 90%) of the Kho-Kho players were found mesomorphic or ectomorphic dominant; because of the specific training programme for Kho-Kho game.

The present study implied a Team Performance Indicator (TPI) to rank all of the qualified and non-qualified teams (table 4). The TPI is formulated based on the overall scoring by an individual team per match played. The greater the credit of the TPI, the higher the team's rank. As a result of the TPI, all of the qualified teams received the top three rankings (ranks 1, 2 & 3). The non-qualified received lower ranks, indicating that there might be some performance difference exist between the qualified and non-qualified teams in terms of scoring.

A statistical comparison of the morphological traits of the five out of nine identified somatotypes has been presented in table 5. The analysis revealed that these five somatotypes accounted for 90% of the Kho-Kho players in the study. The players possessing mesomorphic-ectomorph somatotypes, showed a significant difference in the mesomorphic traits ( $p = 0.010$ ) of the players of the qualifier and non-qualifier teams and the ectomorphic traits ( $p = 0.001$ ) (table 5). In the ectomorphic-mesomorph group (table 5), the mesomorph feature showed a significantly higher mean value in the players of qualified team (mean = 5.14) compared to the players of non-qualified team (mean = 4.16). Similarly, there was also a significant difference ( $p$ -value of 0.044\*) exist in the ectomorph characteristic between the players of qualified and the players of non-qualified teams in the ectomorphic-mesomorph group. While assessing the mesomorph-ectomorph somatotypes, it was found that both mesomorphic traits (0.04) and the ectomorphic traits (0.04) were significantly higher in the players of the qualified teams (table 4).

A similar result achieved by Manohar (2015) while studying on medallists and non-medallist Kho-Kho players. Medallist players were shown to have more mesomorphic and ectomorphic features than non-medallist players, and they are predominantly mesomorphic-ectomorphs. The result found in the current study also very much accordance with the study done by Arjunan (2015) on the college level kho-kho players. It was found that mesomorphic and ectomorphic traits were significantly dominant but endomorphic traits were not a significantly dominant while compare with other two morphic traits (Arjunan, 2015). Moreover, the study indicated that when comparing the balanced mesomorph and balanced ectomorph somatotypes, there were no significant differences in any of the three somatic traits between the players of qualifying and non-qualifying teams. In the case of balanced-morphic somatotypes, all three somatic traits carry a comparable weight while defining the somatotyping. It could be inferred that in activities where endomorphic traits are more influential in determining body types; mesomorphic or ectomorphic traits may not have as significant an impact.

The data presented in table 4 and table 5 highlighted characteristics differences between players from qualified and non-qualified teams. These differences were evident from the both TPI and the attributes of somatic traits found among players from qualified and non-qualified teams. The findings from table 5 showed that significant difference exists in mesomorphic and ectomorphic traits of the players in three out of five somatotypes. These three specific somatotypes identified in the present study were mesomorphic-ectomorph, ectomorphic-mesomorph and mesomorph-ectomorph. It is noteworthy that players from all these three body types were solely accounted for the 70% of the players considered in this study. Based on the evidence uncovered in the results (table 4 & 5), the present study proceeded to investigate the specific morphic traits that exert influence while defining the somatotypes of EZIU Kho-Kho players.

The results of discriminant analysis identified the specific the somatic traits that have the most impact on the body types of the EZIU Kho-Kho players (table 6). The discriminant coefficient measures the effectiveness of the variable for the discrimination (Jhonson & Wichern, 2007). Higher value of the discriminant coefficient indicates higher discriminating power. In the present study it was found that ectomorphic trait was the most powerful discriminant variable and followed by the mesomorphic traits among the Kho-Kho players of EZIU 2023 (table 6). Having ectomorphic and mesomorphic dominant somatotypes have more advantages for the game like Kho-Kho which demands sudden acceleration, leg explosiveness and ability to change the direction (Joshi & Kalode., 2019; Rathore & Singh, 2014). The group centroid represents how the groups were clearly distant apart on the basis of discriminant functions for each group, i.e., qualified teams and non-qualified teams. The centroid value of qualified team (1.268) distinguishably indicated that players of qualified teams possessed better attributes of somatic traits which was suitable for the playing nature of the Kho-Kho game (table 6).

The coefficient of Wilk's lambda in discriminant analysis verifies the significance of the discriminant model as whole. The range of the Wilk's Lambda value lies between 0 to 1 in linear discriminant analysis. As the resulted value closer

to 0, the significance level becomes higher. The value of 0.373 for Wilk's lambda in the present study indicating a higher significant level of the discriminating model in the present study (Everitt & Horthron, 2006). Additionally, the eigenvalue of the present study clearly supporting the discriminant function of the present study with a coefficient of 1.683a. This eigenvalue coefficient clearly explained adequate amount of variance in the categorical variables exist for the support of the present model. Along with this predicted model has been accurately able to predict 88.6% of the original cases in this study (table 6).

## Conclusions

The study highlighted that ectomorph and mesomorph dominants traits can be a one of the basic criteria for the selection of Kho-Kho players from the East Zone India. Moreover, the attributes of the dominant somatic traits could be also defining factor for the performance level. Though future studies are needed to establish direct impact of somatic traits and the performance. According to the objective, the study was successfully able to assess the specific somatotypes and somatic dominant traits for the Kho-Kho players. Additionally, study also signified the areas where the similar somatotypes differ in terms of somatic attributes among the players of qualified and non-qualified teams.

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## Conflicts of interest

All the authors in the present study has declared no conflicts of interest with respect to authorship and publication of the study.

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## СОМАТОТИПИ МІЖУНІВЕРСИТЕТСЬКИХ ГРАВЦІВ У ХО-ХО В РЕГІОНІ СХІДНА ІНДІЯ

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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., 26 джерел.

**Історія питання.** Соматотипування в сучасному спорті може бути важливим фактором, який слід брати до уваги. Інші дослідження вже зробили перший крок для визначення спортивних соматотипів для інших ігор і видів спорту. На відміну від гри хо-хо, були зроблені певні спроби виявити соматотипи, характерні для цих ігор. Але було проведено лише кілька досліджень, а різні області досі чекають на дослідження.

**Мета дослідження.** Метою цього дослідження було визначити специфічні соматотипи гравців у хо-хо. Крім того, у цьому дослідженні також була зроблена спроба вивчити важливі соматичні риси, які впливають на соматотипи гравців у хо-хо.

**Матеріали та методи.** Для участі в дослідженні було цілеспрямовано відібрано загалом 74 гравці із шести команд гравців у хо-хо, які брали участь у міжуніверситетському турнірі регіону Східна Індія. Збір антропометричних даних проводили відповідно до стандартних процедур, наданих ISAK (Міжнародне товариство з розвитку кінантропометрії). Статистичний аналіз проводили з використанням MS Excel (2021) та SPSS'23.

**Результати.** Результати дослідження показали, що більшість гравців у хо-хо (90, 6%) мали ектоморфні та мезоморфні домінуючі риси. Також була виявлена статистично значуща різниця в ектоморфних і мезоморфних рисах серед гравців із соматотипами мезоморфний-ектоморф ( $p < 0,05$ ), ектоморфний-мезоморф ( $p < 0,05$ ) і ектоморф-мезоморф ( $p < 0,05$ ). Крім того, результати дискримінантного аналізу також показали, що атрибути ектоморфних рис (коефіцієнт дискримінації = 1, 168) і мезоморфних рис (коефіцієнт дискримінації = 0, 812) є важливими соматичними рисами для гравців у хо-хо. Взагалі, 88, 6% вихідних випадків були правильно представлені дискримінантним аналізом.

**Висновки.** Це дослідження показало, що гравці в хо-хо здебільшого мають ектоморфний і мезоморфний домінуючі соматотипи. Крім того, на підставі результатів дослідження можна також зробити висновок, що соматичні атрибути подібних типів статури також відіграють важливу роль для визначення рівня результативності гравців.

**Ключові слова:** антропометричний, ектоморф, мезоморф, ендоморф, дискримінантний аналіз.

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ORIGINAL SCIENTIFIC ARTICLE

## AN ASSESSMENT OF MAXIMAL ISOMETRIC HAND GRIP STRENGTH AND UPPER BODY EXPLOSIVE STRENGTH AND ENDURANCE IN VARIOUS BALL SPORTS

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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.** Playing with the ball and using hand-arm strength and power are very crucial for ball game players. It takes arm force and endurance, as well as isometric hand grip strength, to accomplish ball-game skills.

**Study purpose.** The aim of the study was to evaluate maximal isometric hand grip strength, arm and shoulder explosive strength, and endurance in basketball, handball, and volleyball athletes.

**Materials and methods.** The study randomly selected 135 male athletes, including 45 basketball, 45 handball, and 45 volleyball players, aged 17 to 24, all competing at the inter-university level. Hand grip strength (HGS) for both dominant (DHGS) and non-dominant (NDHGS) hands was measured using a JAMAR hydraulic hand grip dynamometer. An over-the-head seated medicine ball throw (SMBT) test assessed explosive arm strength, while a push-up (PU) test evaluated muscular strength and endurance.

**Results.** The F-values (F) (2, 132) of DHGS, NDHGS, SMBT, and PU tests among basketball, handball, and volleyball players were 0.499 ( $p = 0.608$ ); 1.166 ( $p = 0.315$ ); 5.595 ( $p = 0.005$ ); and 10.339 ( $p = 0.000$ ), respectively. The results indicated that no notable distinctions were observed in DHGS and NDHGS among athletes in the three sports. However, considerable differences were found in the SMBT and PU tests.

**Conclusions.** The study concluded that basketball, handball, and volleyball players' maximum isometric hand grip strength was nearly the same, but in both cases, the handball player's mean value was superior to others. Upper-body explosive power, muscular strength, and endurance showed distinct differences from one group to another.

**Keywords:** hand grip strength, hand dynamometer, upper-body explosive power, muscular strength and endurance, ball sports.

### Introduction

The term "ball game player" describes athletes who participate in sports where a ball is the main object of play. Basketball, handball, volleyball, soccer, baseball, rugby, cricket, hockey, and a host of other sports can be considered among these. Players of these games often compete alone or in teams, aiming to win points by strategically moving the ball while adhering to the rules and regulations of their chosen game. In ball games, players need significant arm strength, endurance, and a strong hand grip to effectively engage in play. These abilities are crucial for executing a variety of movements such as serves, throws, spikes, blocks,

and tackles, which demand not only strength but also endurance in the arms and a strong isometric grip (Reichert et al., 2023). Moreover, both everyday activities and several sports necessitate strong, concentrated contractions of the forearm and hand flexor muscles (Ziyagil et al., 2015).

Handgrip strength is the maximum force when someone voluntarily clasps their fingers together, usually measured in standard conditions with a normal range of motion (Richards et al., 1996; Bohannon, 1997; Gandhi et al., 2010). An individual's muscular strength can be estimated by one's handgrip strength (Foo et al., 2007; Ling et al., 2010). It is one of the most accurate clinical methods for assessing strength and is considered an important indicator of general health (Häger-Ross & Schieber, 2000; Gros Lambert et al., 2002). Additionally, it's effective in assessing upper limb muscle strength, serving as a useful predictor of muscle strength and

endurance (Nara et al., 2022; Vaidya & Nariya, 2021). Hand-grip strength is crucial for catching, throwing, and passing the ball in various team sports. Fingers will also spread less widely when they are longer and the surface material of the hand is greater than what is needed to grasp an object (such as a ball), making grasping more efficient and less tiring (Nag et al., 2003). So, all ball sports demand hand grip strength to hold an object, a ball, or an opponent. Theoretically, players with outstretched fingers and a large flat hand may also have stronger grip strength (Visnapuu & Jürimäe, 2007). The ability to grasp objects firmly is employed as a measure of general physical strength and a practical indicator of physical perfection. This form of energy is influenced by various physiological metrics such as age, sex, exercise, and physical dimensions (Jayanthi, 2018). As isometric tests only require a single maximal contraction and relatively basic equipment, they are simple to carry out. Due to the requirement of an adequate level of grip strength in sports like handball, volleyball, tennis, and basketball, the evaluation of handgrip strength is of the utmost importance (Khanna & Koley, 2020). Hand morphology and functional characteristics may have a significant role in the performance of ball games where the use of the hand is important (Barut et al., 2008). Researchers Borges Junior et al. (2009) suggest that maximal isometric grip strength (Fmax) serves as a useful metric for contrasting different sports disciplines and for distinguishing between dominant and non-dominant hands.

The medicine ball throw test is performed to measure an athlete's upper body explosive power, strength, and coordination of their core, upper limb, and trunk muscles, which are necessary to generate the force and speed required for throwing, shooting, passing, hitting, or spiking. The Seated Medicine Ball Throw (SMBT) test is widely used to evaluate bilateral upper body strength and power across various populations. It has been utilized in research involving male athletes (Read et al., 2013; Santos & Janeira, 2012; Stockbrugger & Haennel, 2003), female athletes (Cronin & Owen, 2004; Jones, 2014), older athletes (Harris et al., 2011), as well as college and university students (Clemons et al., 2010; van den Tillaar & Marques, 2013). Additionally, it is a useful tool for assessing healthy, non-athletic individuals (Vossen et al., 2000). Researcher Suntharalingam et al. (2022) suggest that combining medicine ball exercises with regular training can notably enhance both physical and basketball-specific skills. It is a convenient, affordable, and low-tech tool that can be used to monitor athletes on the field to discover talent and anaerobic power (Kumar et al., 2021a). This test serves as a valuable tool for evaluating upper-body explosive ability, providing insight into how an athlete performs in this particular aspect. The push-up test (arms 90° angle) is widely employed to assess the durability and stamina of the arms and upper body muscles (Yıldırım et al., 2022; Kellner et al., 2021; Baumgartner et al., 2002). To build pectoralis major and triceps brachii strength for athletic exercise and performance, perform push-ups as a strength exercise (Cogley et al., 2005; Mayhew et al., 1991). The chest, shoulders, triceps, and core are all muscles that are worked with push-up, a simple bodyweight exercise. Success in various ball sports, including basketball, handball, and volleyball, depends on upper body strength, muscular endurance, and stability. This test involves measuring how many push-ups a person can do within a certain time frame.

In evaluating sports performance, push-up tests are of significant importance.

Overall, hand grip strength, upper body explosive power, and push-up exercises are integral to enhancing performance in various ball sports such as basketball, handball, and volleyball. These games are similar in nature and style of play, as hand strength, arm and upper body strength, and endurance are used similarly. Due to similar practice and training opportunities, university-level athletes in these three sports probably have comparable grip strength, explosive power, and endurance. Therefore, the present study compares hand, arm, and upper body function in different university level ball sports, specifically basketball, handball, and volleyball. The function of the hand was assessed through hand grip strength, while tests involving the medicine ball throw and push-ups measured arm strength, upper body explosive strength, and endurance.

## Materials and Methods

### Participants

A total of one hundred thirty-five (N=135) male athletes were randomly selected for this study, among them (n=45) basketball players, (n=45) handball players, and (n=45) volleyball players. The subjects were between the ages of 17 to 24, and at least they had competed in their respective sports at the inter-university competition. All the participants (subjects) were chosen from ten public universities in Bangladesh.

**Table 1.** Differences data (mean ± SD) and ANOVA of the subjects

| Variables                | Basketball<br>(n=45) | Handball<br>(n=45) | Volleyball<br>(n=45) | ANOVA  |
|--------------------------|----------------------|--------------------|----------------------|--------|
| Age (yrs)                | 22.04±1.21           | 21.69±1.68         | 21.82±1.85           | 0.569  |
| Height (cm)              | 177.78±6.75          | 170.44±6.37        | 174.26±7.08          | 0.000* |
| Weight (kg)              | 71.84±6.75           | 66.41±7.87         | 68.03±8.66           | 0.004* |
| BMI (kg/m <sup>2</sup> ) | 22.72±1.65           | 22.82±1.92         | 22.38±2.35           | 0.558  |

BMI = body mass index; \* = significant difference at 0.05 level

### Instruments

For anthropometric measurements of height and weight, a KRUPS stadiometer (India) and an OMRON digital weighing scale (India) were used. The BMI was then determined using the following formula: weight (kg)/height(m)<sup>2</sup>. The maximal isometric DHGS and NDHGS were measured with the help of a JAMAR (USA) hydraulic hand grip dynamometer. Upper body (arms) strength and explosive power were measured for the SMBT (MDBuddy medicine ball, China) test, and muscles strength and endurance were assessed using the PU test.

### Procedure

#### DHGS and NDHGS tests

The maximal isometric grip strength of the DHGS and NDHGS were measured with the help of a JAMAR (Model

J00105) hydraulic hand dynamometer (Lafayette Instrument, Lafayette, IN, USA) (Hepping et al., 201). For this test, the subject was seated comfortably on a chair with his back straight, abduction and flexion of the shoulder and elbow were 0° and 90°, respectively. Then the subject was asked to use a comfortable grip position (second handle position) and proper technique for the grip strength measurements. As soon as everyone is seated correctly, say, squeeze as firmly as you can—harder!—harder!—then relax. The peak-hold needle automatically recorded his highest exerted force. Before taking new readings, reset the peak-hold needle to zero (Dynamometer, 2004). Tests were taken in the sequence of dominant hand followed by non-dominant hand, and the time interval between the two tests was 30 seconds. As the final score, the mean of the three trials was used, which is in kilograms.

### SMBT test

Upper limb explosive strength was measured through an SMBT (MDBuddy; Nantong Modern Sporting Industrial Co., Ltd., Jiangsu, China) test. The medicine ball is a round shape made of rubber, and the gripping surface is very good. For this, a 2-kg medicine ball is required, and the subject was seated comfortably on the chair with his upper body erect and both legs touching the ground. Subjects were asked to warm up properly, lift the medicine ball up with both hands, and throw the ball forward with maximum force (like a football throw-in). During this time, the body cannot be moved backwards or forwards, and of course, the body is against the back of the chair. The horizontal distance was measured in meters between where the base of the chair begins and the bottom of the throw. A total of three throws were made, and there was a one-minute break in between. Arm strength and explosive power were obtained by measuring the highest distance in meters.

### PU test

Arm and shoulder muscle strength and endurance were measured using the push-up test, which requires the muscles to perform rapid, repetitive movements for a specified period

of time. To begin the test, the subjects place both palms on the floor with shoulders extended, elbows straight, and the lower back (knees) straight. As the time started, the subject was touching his body towards the floor until the elbows were at 90°. Repeat fast until the 30 seconds are up. A Casio Digital Stopwatch (Casio Electronics Co., Ltd., China) was used for recording time, and the total number of push-ups was counted.

### Statistical analysis

Statistical evaluation was performed using IBM's SPSS version 20 for Windows, located in Chicago, IL, USA. Descriptive metrics were calculated for each group. To detect significant differences in data, one-way ANOVA, LSD post-hoc analysis and independent t-test were employed with significance level set at 0.05. Levene's test was utilized to assess the homogeneity of variances, which confirmed normal data distribution.

### Results

Table 3 indicates that the observed differences were not statistically significant between groups for variables such as DHGS ( $F_{(2, 132)} = 0.499$ ,  $p = 0.608$ ), and NDHGS ( $F_{(2, 132)} = 1.166$ ,  $p = 0.315$ ). In the study, the DHGS and NDHGS of basketball, handball, and volleyball players were about the same, but in two cases, the handball player's average value was higher than the others. The data revealed a significant difference between groups for the given variables, namely, SMBT and PU tests ( $F_{(2, 132)} = 5.595$ ,  $p = 0.005$ ), and ( $F_{(2, 132)} = 10.339$ ,  $p = 0.000$ ), respectively.

The post-hoc (LSD) test showed that the SMBT test was statistically significant difference between the handball ( $6.2347 \pm 0.74198$ ,  $p = 0.035$ ) and basketball ( $5.8760 \pm 0.90564$ ,  $p = 0.035$ ) groups as compared to the volleyball ( $5.6789 \pm 0.73829$ ). Again, there was a statistically significant difference between handball and volleyball ( $p = 0.001$ ); and no significant difference between basketball and volleyball ( $p = 0.244$ ). For the PU test, the basketball, handball, and volleyball groups were all statistically significantly different ( $p = 0.017$ ;  $0.035$ ;  $0.000$ ), respectively.

**Table 2.** Descriptive statistics

| Variables  | Players    | N  | Mean    | Std. Dev. | Std. Error | Minimum | Maximum |
|------------|------------|----|---------|-----------|------------|---------|---------|
| DHGS (kg)  | Basketball | 45 | 48.3971 | 8.12343   | 1.21097    | 28.33   | 74.00   |
|            | Handball   | 45 | 49.4191 | 7.21703   | 1.07585    | 35.33   | 70.33   |
|            | Volleyball | 45 | 47.8933 | 6.73616   | 1.00417    | 33.66   | 64.33   |
| NDHGS (kg) | Basketball | 45 | 46.5738 | 8.98924   | 1.34004    | 26.33   | 71.33   |
|            | Handball   | 45 | 47.4636 | 8.31380   | 1.23935    | 30.00   | 68.00   |
|            | Volleyball | 45 | 44.8709 | 7.14454   | 1.06504    | 31.33   | 60.66   |
| SMBT (m.)  | Basketball | 45 | 5.8760  | 0.90564   | 0.13500    | 4.10    | 7.97    |
|            | Handball   | 45 | 6.2347  | 0.74198   | 0.11061    | 4.82    | 8.25    |
|            | Volleyball | 45 | 5.6789  | 0.73829   | 0.11006    | 4.17    | 7.00    |
| PUT(No.)   | Basketball | 45 | 26.311  | 60.4976   | 0.9686     | 17.0    | 42.0    |
|            | Handball   | 45 | 29.911  | 7.5342    | 1.1231     | 14.0    | 46.0    |
|            | Volleyball | 45 | 23.133  | 7.1529    | 1.0663     | 10.0    | 40.0    |

**Table 3.** One-way ANOVA of selected parameters of basketball, handball, and volleyball players

| Variables | Groups         | Sum of Squares | df  | Mean Square | F-ratio | p-value |
|-----------|----------------|----------------|-----|-------------|---------|---------|
| DHGS      | Between Groups | 54.394         | 2   | 27.197      | 0.499   | 0.608   |
|           | Within Groups  | 7191.867       | 132 | 54.484      |         |         |
| NDHGS     | Between Groups | 156.202        | 2   | 78.101      | 1.166   | 0.315   |
|           | Within Groups  | 8842.677       | 132 | 66.990      |         |         |
| SMBT      | Between Groups | 7.146          | 2   | 3.573       | 5.595   | 0.005   |
|           | Within Groups  | 84.295         | 132 | .639        |         |         |
| PUT       | Between Groups | 1034.948       | 2   | 517.474     | 10.339  | 0.000   |
|           | Within Groups  | 6606.489       | 132 | 50.049      |         |         |

\*. Significant at 0.05 level

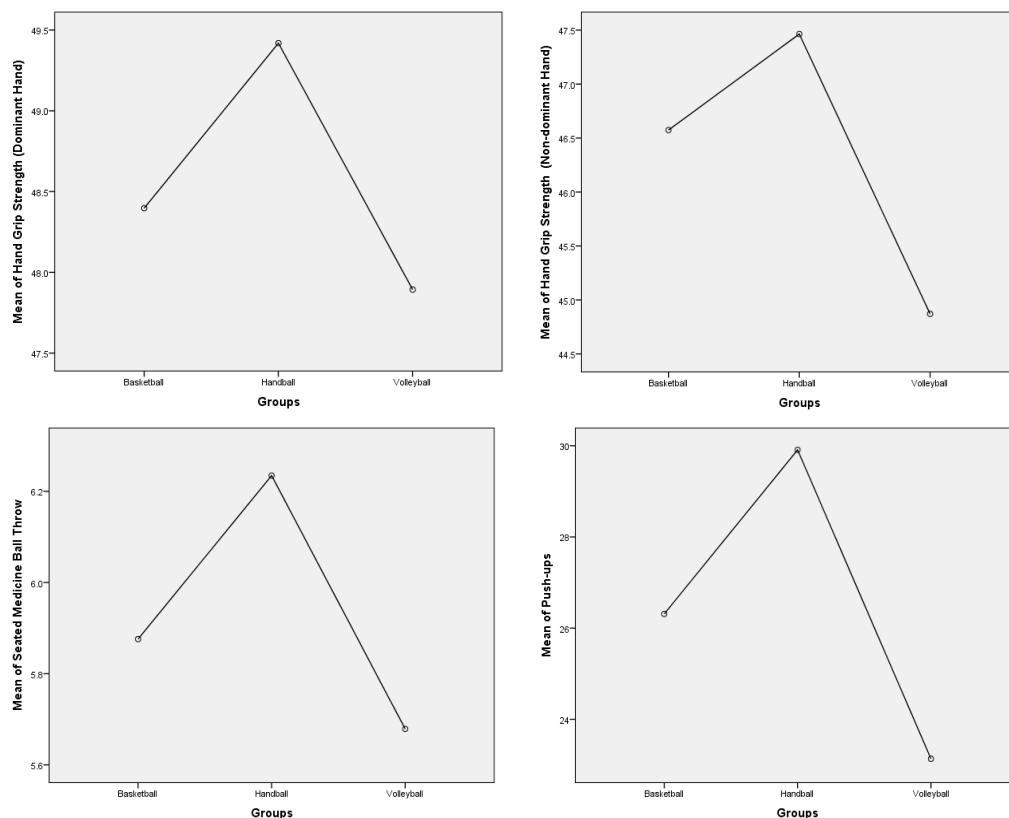


**Fig. 1.** Mean plots of variables in three groups

**Table 4.** Post-hoc (LSD) test

| Variables  | Groups     | Groups     | Mean Diff. | Std. Error | Sig. Level |
|------------|------------|------------|------------|------------|------------|
| SMBT       | Basketball | Handball   | -0.35867*  | 0.16847    | 0.035      |
|            |            | Volleyball | 0.19711    | 0.16847    | 0.244      |
|            | Handball   | Basketball | 0.35867*   | 0.16847    | 0.035      |
|            |            | Volleyball | 0.55578*   | 0.16847    | 0.001      |
| PU         | Basketball | Basketball | -0.19711   | 0.16847    | 0.244      |
|            |            | Handball   | -0.55578*  | 0.16847    | 0.001      |
|            | Handball   | Handball   | -3.6000*   | 1.4914     | 0.017      |
|            |            | Volleyball | 3.1778*    | 1.4914     | 0.035      |
| Volleyball | Basketball | Basketball | 3.6000*    | 1.4914     | 0.017      |
|            |            | Volleyball | 6.7778*    | 1.4914     | 0.000      |
|            | Handball   | Basketball | -3.1778*   | 1.4914     | 0.035      |
|            |            | Handball   | -6.7778*   | 1.4914     | 0.000      |

\*. The mean difference is significant at the 0.05 level

Independent t-tests revealed a significant difference in the strength of hand grip between DHGS and NDHGS in basketball, handball, and volleyball players:  $t(268) = 2.392$ ,  $\text{sig.} = .017$  (2-tailed),  $p < 0.05$ . However, DHGS was higher among the three groups.

## Discussion

According to the table 3 analysis, no significant difference was obtained in DHGS and NDHGS among basketball, handball, and volleyball players. Likewise, researcher Barut et al. (2008) conducted a study on handgrip strength across different sport groups. The results revealed that there was no noteworthy variation in the grip strength of the left and right hand among male participants engaged in basketball, handball, and volleyball. Similarly, Çolak (1995) evaluated male athletes in volleyball, basketball, and football, and the findings indicated that soccer players exhibited the highest

**Table 5.** Independent t-test between DHGS and NDHGS of three groups together

| Item               | Parameters | Mean (kg) | Std. Deviation | t     | df  | Sig. (2-tailed) |
|--------------------|------------|-----------|----------------|-------|-----|-----------------|
| Hand Grip Strength | DHGS       | 48.5699   | 7.35368        | 2.392 | 268 | 0.017           |
|                    | NDHGS      | 46.3027   | 8.19486        |       |     |                 |

Significant at 0.05 level

grip strength in both hands. However, differences in grip strength between groups did not reach statistical significance for other sports. In a study by Yüksel (2017), the grip strength of male Turkish basketball players across different leagues was analyzed. The findings indicated no notable difference in the grip strength of the right and left hands between the two leagues. Based on the research's Kararkoç et al. (2015) findings, it can be said that athletes who participate in various sports, including judo, badminton, handball, basketball, and football, have the same grip strength in both the left and right limbs. Also, athletes in volleyball, basketball, table tennis, and tennis all have similar average left hand grip strengths (Duran, 2021). According to Fallahi and Jadidian (2011) conducted a study on grip athletes in sports such as basketball, handball, volleyball, and wrestling, where grip strength is important, and found that they had more dominant and non-dominant hand grip strength than those not involved in any athletic activity. Similar studies were done by other sports and subjects, and the results suggest that there is no major disparity in dominant and non-dominant hand grip strength in field hockey players (Koley & Kaur, 2017), male elite and sub-elite weightlifters (Erdağı, 2020), and athletes from various sports like hockey, tennis, badminton, cricket (Joseph et al., 2021), basketball, and netball (Kumar et al., 2021b). Researcher Eler and Eler (2018) found no statistical difference between right-hand and left-hand grip strength in four disciplines of male racket sports (tennis, squash, table tennis, and badminton). A six-pound medicine ball throw was used to demonstrate that basketball players' arms have more explosive strength than volleyball players' arms (Suma & Giridharaprasath, 2022). In another study, compared to volleyball players, handball players had higher shoulder strength in their unilateral and bilateral seated medicine ball throwing ability (Saccol et al., 2022). Muscular endurance showed a notable variation between university-level basketball and handball players when measuring muscle strength through the push-ups test (Pandian & Divya, 2022). The data in Table 5 indicates that there are meaningful statistical variances in grip strength between the DHGS and NDHGS across all three groups, with the dominant hand always exhibiting greater strength. Prior research that included both right- and left-handed participants also demonstrated that the dominant hand had a notably stronger grip in all evaluations, corroborating earlier findings (Armstrong & Oldham, 1999; Incel et al., 2002). Grip strength is significantly different between the dominant and non-dominant hands of male and female athletes in basketball, handball, volleyball, and badminton (Kaplan, 2016). In a study by Massuçça et al. (2014) between premier and non-premier handball athletes, the preferred hand exhibited noticeably more powerful grip strength (2.15 kg difference,  $p < 0.05$ ). Handgrip strength was measured in 544 young Italian adults (18–30 years) in relation to handedness, and the results showed that dominant hands had higher HGS

than non-dominant hands, and ambidextrous individuals had a stronger right hand (Zaccagni et al., 2020).

In summary, handball is a physically demanding contact sport that relies heavily on the upper body, hands, and arms for both offensive and defensive aspects. Players use their bodies to connect with opponents, requiring substantial upper body strength for effective technique. Defenders in handball engage in physical battles, relying on their upper body strength to push, block, and intercept opponents. Explosive power generated by the upper body is crucial for powerful throws and scoring opportunities. In this research, it is observed that handball distinguishes itself from less contact-based sports such as basketball and volleyball.

## Conclusions

The findings of the research showed that the peak isometric grip strength among athletes in basketball, handball, and volleyball was fairly comparable. Nevertheless, handball players demonstrated superior average grip strength compared to those in the other two sports. Additionally, there were notable disparities in areas like upper-body explosive force, muscle strength, and endurance between the groups. These variations highlight the distinct physical attributes and training regimes across these three sports.

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## Conflicts of interest

The authors declare no conflicts of interest.

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## ОЦІНКА МАКСИМАЛЬНОЇ ІЗОМЕТРИЧНОЇ СИЛИ СТИСНЕННЯ КИСТІ ТА ВИБУХОВОЇ СИЛИ ВЕРХНЬОЇ ЧАСТИНИ ТІЛА Й ВИТРИВАЛОСТІ В РІЗНИХ СПОРТИВНИХ ІГРАХ ІЗ М'ЯЧЕМ

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

Реферат. Стаття: 8 с., 5 табл., 1 рис., 53 джерела.

**Історія питання.** Гра з м'ячем і використання сили й потужності кистей і рук дуже важливі для гравців в ігри з м'ячем. Для вдосконалення навичок гри з м'ячем потрібна сила та витривалість рук, а також ізометрична сила стиснення кисті.

**Мета дослідження.** Метою цього дослідження було оцінити максимальну ізометричну силу стиснення кисті, вибухову силу рук і плечей, а також витривалість у баскетболістів, гандболістів і волейболістів.

**Матеріали та методи.** Для участі в дослідженні були випадковим чином відібрані 135 спортсменів чоловічої статі, у тому числі 45 баскетболістів, 45 гандболістів і 45 волейболістів, віком від 17 до 24 років, які всі беруть участь у змаганнях на міжуніверситетському рівні. Силу стиснення кисті (HGS) як для домінантної (DHGS), так і для недомінантної (NDHGS) руки вимірювали за допомогою гідравлічного ручного динамометра JAMAR. Для оцінки вибухової сили рук використовували тест на кидок медичного м'яча через голову з положення сидячи (SMBT), а для оцінки м'язової сили та витривалості використовували тест на віджимання (PU).

**Результати.** Значення F-величин (F) (2, 132) тестів DHGS, NDHGS, SMBT та PU серед баскетболістів, гандболістів і волейболістів становили 0,499 ( $p = 0,608$ ); 1,166 ( $p = 0,315$ ); 5,595 ( $p = 0,005$ ); та 10,339 ( $p = 0,000$ ) відповідно. Результати показали, що жодних помітних відмінностей у тестах DHGS та NDHGS серед спортсменів у всіх трьох видах спорту не спостерігалось. Проте в тестах SMBT та PU були виявлені значні відмінності.

**Висновки.** На підставі результатів дослідження зроблено висновок, що максимальна ізометрична сила стиснення кисті в баскетболістів, гандболістів і волейболістів була приблизно однаковою, але в усіх випадках середнє значення гандболістів було вищим, ніж в інших. Показники вибухової сили верхньої частини тіла, м'язової сили та витривалості показали чіткі відмінності в різних групах.

**Ключові слова:** сила стиснення кисті, ручний динамометр, вибухова сила верхньої частини тіла, м'язова сила та витривалість, спортивні ігри з м'ячем.

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ORIGINAL SCIENTIFIC ARTICLE

## TEST CONTROL OF INCLUSIVE PHYSICAL EDUCATION: ASSESSMENT USING THE NEWEST ELECTRONICS

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### Abstract

**The purpose of the study** was to determine the effectiveness of a device developed based on the latest electronics to control the coordination of movements of the lower limbs of students with disabilities.

**Materials and methods.** 34 students with disabilities were involved in the study. At the time of the experiment, they had functional disorders of the lower limbs as a result of injuries and received a doctor's permission to participate in the experiment. The research was conducted at the theoretical and empirical levels, using the following methods: analysis, synthesis, systematization, generalization, technical modeling, pedagogical testing, and mathematical statistics.

**Results.** In the research process, a device was used, which was developed as part of the conducted research. The device consists of two rubber mats in which capacitive proximity sensors are placed. The test task involves recording the number of touches of rubber mats in 20 seconds. The information received from the sensors during the student's performance of the test task, namely the alternate touching of the rubber mat with the big toe, is sent to the microcontroller via an infrared communication line. The development uses a high-performance microcontroller ATMega 328P, which can support a wide range of sensors and generate information about the time and frequency of leg movements. The signals of the student's toes touching the rubber mats, received by capacitive sensors, are processed by a microcontroller and displayed on a PC through a serial connection and using the Arduino software, which allows reading the received information about the execution of movements. Under the conditions of the pedagogical experiment, we tried to determine the quality of the measurement results. According to the obtained numerical indicators, the numerical values of the test authenticity obtained by the traditional method of fixing the results by a specialist correspond to the value "low". The results of the validity calculations showed that the correlation between the test measurement results and the evaluation results using the developed device was optimal with a correlation coefficient greater than 0.6.

**Conclusions.** The importance of a high level of development of the coordination of movements of the lower limbs of students with disabilities is determined by the need to develop this quality to ensure the effectiveness of their rehabilitation in the process of inclusive PE. The analysis of the obtained material allows us to state that the practical application of the inclusive PE device developed based on the latest electronics will allow scientifically based optimization of this process to ensure its effectiveness.

**Keywords:** students with disabilities, physical education, testing, inclusion, control, coordination of lower limb movements.

### Introduction

Problem statement. Russia's open military attack on Ukraine in 2022 and long-term Russian aggression have be-

come a factor in the fact that the number of people affected by the war in Ukraine is constantly increasing. It is natural that among the entrants to higher education institutions, the number of persons with disabilities who received injuries and permanent limitations of life activities as a result of participation in hostilities and emergencies increases annually (Blavt, Bodnar, Mykhalskyi, Gurtova, & Tsovk, 2023).

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In connection with the latter, the process of attracting and preventing the exclusion of students with disabilities from the conditions of study in the process of obtaining higher education – their successful inclusion – acquires special significance (Page, Anderson, & Charteris, 2021). Since the full-scale invasion of Russia on the territory of Ukraine, attention has increased to the problems of inclusion of students with disabilities, which today is one of the most pressing issues of higher education (Blavt, Iedynak, Pereverzieva, Holub, & Melnyk, 2023).

One of the effective means of inclusion in higher education is considered inclusive PE (Kuntjoro, Soegiyanto, Setijono, & Suharto, 2022).

Making qualitative changes in the process of inclusive FP for its productive development requires constant monitoring of the expediency of using a wide range of FP tools (Hutzler, & Levi, 2008). In this aspect, the synergy of efforts of different fields of knowledge involves the use of high-tech measuring devices, which allows for quantitative evaluation of the results of inclusive PE (Mykytyuk, Blavt, Hnatchuk, Stechkevych, & Helzhynska, 2022).

Analysis of recent research and publications. The scientific interest of researchers from different countries of the world is focused on the possibilities of inclusive PE as an effective means of preserving the health, well-being, and inclusion of persons with disabilities (Pocock, & Miyahara, 2018; Wilhelmsen, & Sørensen, 2017; Nemček, 2022). Currently, there is a fairly wide list of empirical studies (Baglieri, & Bacon, 2020; Grenier, Patey, & Grenier-Burtis, 2022; Pellerin, Wilson, & Haegele, 2022) regarding the value of inclusive PE in the implementation of rehabilitation of students with disabilities.

According to data from scientific sources (Nanayakkara, 2022; Grenier, Patey, & Grenier-Burtis, 2022; Wolbring, & Lillywhite, 2021), inclusive PE for students with disabilities who have suffered injuries is a means of preventing serious mobility limitations, postural disturbances, reduced body endurance and inability to tolerate physical exertion. According to ideas (Davis, Rocco-Dillon, Grenier, Martinez, & Aenchbacker, 2012; Desrosiers, Rochette, & Corriveau, 2005), an important place in this process to increase the chances of maximum recovery and return to a comfortable physical state of students with disabilities is the coordination of lower limb movements.

The importance of lower limb motor coordination is because it enables the performance of most daily motor activities, such as walking, running, climbing/descending stairs, and standing from a chair (Lower\_Limb\_Motor\_Coordination). According to available research (Pinheiro, Scianni, Ada, Faria, & Teixeira-Salmela, 2014), the coordination of lower limb movements is a factor affecting the effectiveness of the rehabilitation process, as a result of its violation, problems with balance and coordination arise due to disorders of the nervous, vestibular, or supporting – motor system (Neto, Steenbergen, Wilson, Zamunér, & Tudella, 2020).

Monitoring and evaluating the effectiveness of the PE process requires a reliable toolkit (Iermakov, Ivashchenko, Khudolii, & Chernenko, 2020). The mainstream in the creation of measurement tools based on high-tech capabilities is the latest electronic technologies (Blavt, Chaplinskyi, Prozar, Pityn, Helzhynska, Dmytruk, Hrebik, & Kovalchuk, 2023).

Empirical studies (Blavt, Iedynak, Pereverzieva, Holub, & Melnyk, 2023; Kashuba, Nosova, Kolomiets, & Maslova, 2019) have proven the effectiveness of using electronic technologies in monitoring PE results (Gupta, 2021; Gogoi, 2019; Varga, & Révész, 2023; Mykytyuk, Blavt, Kachurak, Stadnyk, Gurtova, Diskovskyi, & Barylo, 2022).

Taking into account the consequences of armed Russian aggression on the territory of Ukraine, which are an increase in students with disabilities who received injuries and permanent restrictions on life, and taking into account the practical value of the experience of using the latest electronics in the process of inclusive PE, the direction of scientific research was chosen.

Purpose of the research research in determining the effectiveness of the device developed based on the latest electronics for controlling the coordination of movements of the lower limbs of students with disabilities.

## Materials and methods

### Research methods

The methods chosen for the implementation of our scientific research by the purpose and objectives of the research are characterized by systematicity and structure. Therefore, in conducting empirical research, we were guided by a systematic approach (Ivashchenko, 2020). According to this approach, the first stage of the research involved obtaining complete, objective, reliable information about the feasibility of the outlined scientific research – the theoretical level of research implementation, the second – had a comparative view of the researched issue. At the third stage of the research, according to the system approach, the empirical data obtained during the comparison were summarized. The fourth final stage consisted in the formation of generalized results.

The test chosen for the study to monitor the level of development of coordination of movements of the lower limbs (Pribble, Black, Larson, & Larson, 2021) is the simplest and easiest-to-use exercise that does not require complex equipment. The test case must be performed in a sitting position on a chair. The test procedure lasts less than 1 minute, and therefore the possibility of fatigue is excluded.

*Test procedure.* The student sits on a chair with adjustable height so that the soles of both sides are in contact with the floor. Heels, hips and knees should be in a 90° flexion position. After a trial introduction, the student should alternately touch the disks located on the floor at a distance of 30 cm from each other with his big toe. Movements are

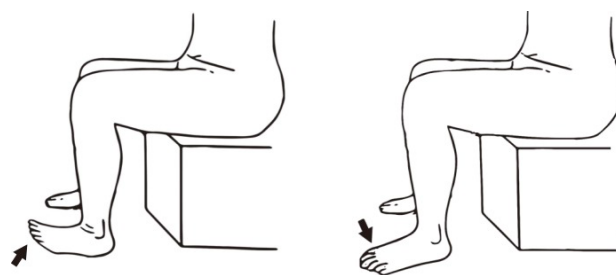


Fig. 1. Scheme of the test

performed for 20 seconds. The number of touches to the discs in 20 seconds is recorded. The toes were required to strike and then “lift-off” the floor during movement.

### Study participants

34 students with disabilities were involved in the study Lviv Polytechnic National University, Kamianets-Podilskyi Ivan Ohiienko National University and Lutsk National Technical University, who at the time of the experiment had functional disorders of the lower limbs as a result of injuries or damage. It is important that all participants of the experiment were diagnosed with injuries of moderate severity in a state of remission. A requirement of the experiment at the time of screening and data collection was the absence of acute conditions, open wounds or complications in students with disabilities. The students with disabilities involved in the experiment independently attended the inclusive PE classes within the educational program and did not need outside help in completing the test task.

Written consent to participate in the experiment was obtained from each student who was planning to be involved in the study. To ensure the representativeness of the studied independent sample, several mandatory conditions for any research were taken into account, namely, every student, in the presence of health abnormalities, received an equal probability of becoming a research participant.

A doctor's permission to participate in the experiment was obtained from all students with disabilities who made up the researched sample. First-year students (men) who voluntarily and anonymously agreed to participate in the experiment to eliminate biases in the collection and analysis of information were involved in the experiment.

Taking into account the fact that the degree of authenticity of the test, which is determined empirically, is significantly influenced by the nature of the sample used to test the test, the conditions of performing motor actions, the level of physical fitness of the students of the studied sample, the degree of existing lesions and the degree of injury to the limbs were taken into account, etc.

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 study was planned and carried out in accordance with the principles of empirical research ethics. The organization of the research involved obtaining empirical facts. The measurement process, to collect empirical test data, is implemented in two ways. First of all, all students with disabilities, who were involved in the experimental study, were given clear instructions on the implementation of the test task.

The experimental factor involved a variation in the method of recording test control results. Fixation of test control results was implemented with the direct participation of a specialist to get rid of the elements of subjectivism of traditional analysis, using the developed control device.

To ensure the reliability of the experiment, testing was carried out during three months of the academic semester, trying to ensure the same conditions. Test participants were provided with precise instructions and formulated tasks.

### Statistical analysis

In order to bring the empirical data obtained during the empirical research to a form more suitable for meaningful analysis, a computer type of processing of the obtained empirical information was chosen. All statistical analyses were performed using SPSS Version 22.0 (IBM Corporation).

The conclusion about the results of the empirical study was made based on establishing the authenticity of the tests. Validity, which indicates its usability and reliability, served as a comprehensive characteristics. To establish the quantitative characteristics of the authenticity of the test and in view of the low labor intensity, correlation analysis was applied (Turney, 2022). Correlation analysis involves measuring two variables and assessing the statistical dependence (correlation) between them.

### Results

First of all, we note that the proper level of coordination of movements of the lower limbs requires temporal and spatial accuracy of movements and ensures the ability to perform motor tasks while walking in an accurate, fast, and controlled manner (Lower limb motor coordination). In turn, objective timely monitoring of the coordination of movements of the lower limbs allows for a standardized understanding of the nature and level of impairments, to assess the level of recovery progress after the consequences of the injury (Hoenig, Amis, Edmonds, Morgan, Landerman, & Caves, 2018).

In the research process, a device was used, which was developed within the framework of the conducted research (Fig. 2). The device consists of two rubber mats in which capacitive proximity sensors are stirred (Hotra, Mahlovanyy, Mykytyuk, Barylo, Kremer, Ivakh, & Politanskyi, 2019). The test task involves recording the number of touches of rubber mats in 20 seconds. The device registers changes in the capacitance of the sensors when the student touches the rubber mats with his toes. The information received

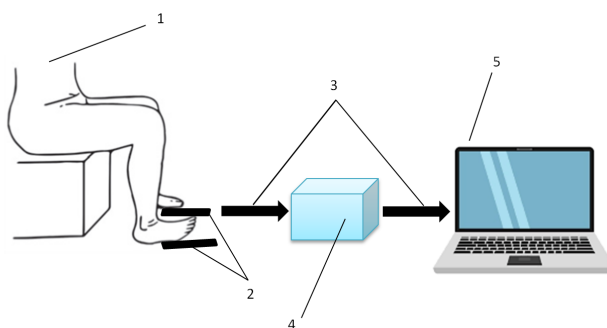


**Fig. 2.** Scheme of the developed device for controlling the coordination of movements of the lower limbs: 1 – student, 2 – rubber mats, 3 – infrared communication lines, 4 – microcontroller, 5 – PC

from the sensors during the student's performance of the test task, namely the alternate touching of the rubber mat with the big toe, is sent to the microcontroller via an infrared communication line. The microcontroller generates information about the time and frequency of leg movements.

The novelty of the proposed development is that the device uses a high-performance microcontroller ATmega 328P of the "latest generation", which can support a wide range of sensors and has a large list of functions (Mykytyuk, Kremer, Ivakh, Diskovskyi, & Khomyak, 2021). This microcontroller contains an internal built-in 32 kB of flash memory, 23 input/output lines, configurable timers and counters, and 5 possible power-saving modes, with the ability to balance power consumption and performance.

The signals of the student's toes touching the rubber mats, received by capacitive sensors, are processed by a microcontroller and displayed on a PC through a serial connection and using the Arduino software, which allows reading the received information of the test task. The device allows you to record and control not only the number of taps but also their duration, rhythm, speed, etc. And the used software allows you to present it graphically.

The developed device ensures that all test control data is collected, analyzed, and available in a single system at any time. This ensures access to all test data on any PC at any time.

Under the conditions of the pedagogical experiment, we tried to determine the quality of the measurement results. The experiment provides for the implementation of the test process three times and the fixation of the results with the correlation of the experimental factor. The results are presented in Table 1.

**Table 1.** Results of the test control of the coordination of movements of the lower limbs (n = 34)

| Statistical parameters | Test tasks and measurement results<br>(Number of times) |       |                         |       |                         |       |
|------------------------|---------------------------------------------------------|-------|-------------------------|-------|-------------------------|-------|
|                        | 1 <sup>st</sup> attempt                                 |       | 2 <sup>nd</sup> attempt |       | 3 <sup>rd</sup> attempt |       |
|                        | T                                                       | A     | T                       | A     | T                       | A     |
| M                      | 27.1                                                    | 33.2  | 25.7                    | 32.1  | 29.3                    | 31.5  |
| S                      | 5.6                                                     | 5.1   | 6.3                     | 4.9   | 6.7                     | 4.7   |
| V (%)                  | 35.2                                                    | 19.7  | 36.1                    | 20.8  | 30.9                    | 19.2  |
| $r_{tt}$               |                                                         |       |                         |       |                         |       |
| reliability            | 0.458                                                   | 0.901 | 0.489                   | 0.909 | 0.504                   | 0.899 |
| validity               | 0.231                                                   | 0.612 | 0.251                   | 0.607 | 0.297                   | 0.633 |

\*T – the traditional way, A – using the developed tool

First of all, it was determined in advance what we wanted to measure. Given that test theory emphasizes the absence of a fixed authenticity value that would allow a test to be considered acceptable (Chaabouni, et al., 2022), the obtained empirical data were used for the final comparative analysis.

According to the obtained numerical indicators, the numerical values of the test authenticity obtained by the traditional method of fixing the results by a specialist correspond to the value "low". Given that the lower limit of acceptable reliability values is usually chosen to be 0.7,

the reliability coefficient of the test as an average measure of measurement accuracy, fixing the result in this way is unjustified due to significant measurement errors, which indicates that this method is time-consuming and inefficient.

According to the results of the calculations, the fixation of the results by the developed control device, the value of the reliability coefficient as internal consistency is  $> 0.9$ , which indicates "very high reliability". Taking into account such a reliability indicator, it can be argued that there is a lower probability of an error in the measurement of an individual result.

Given that reliability is required to achieve validity (Pribble, Black, Larson, & Larson, 2021), the results of the validity calculations showed that the correlation between the results of the test measures and the results of the assessment using the developed device corresponds to the level of "high" with a correlation coefficient greater than 0.6. The calculated coefficients of validity of the tests, where the recording of the results was carried out directly by the teacher, are within the "low" range.

## Discussion

The relevance of our research is the urgent need to implement inclusion in institutions of higher education (Page, Anderson, & Charteris, 2021; Kuntjoro, Soegiyanto, Setijono, & Suharto, 2022). As hostilities on the territory of our country continue, a significant number of defenders return from the war with various injuries, and the number of students with disabilities will only increase in the future. Their full rehabilitation while studying in institutions of higher education is a guarantee of effective functioning, successful social reintegration, and full physical capacity (Blavt, Bodnar, Mykhalskyi, Gurtova, & Tsovkha, 2023).

Therefore, the conducted scientific research corresponds to the needs of modern times and aims to convey the current ideas of inclusion to students (Wolbring, & Lillywhite, 2021). We support scientific approaches (Kuntjoro, Soegiyanto, Setijono, & Suharto, 2022; Nanayakkara, 2022; Grenier, Patey, & Grenier-Burtis, 2022) that, from the point of view of fundamental ethics and respect for each student, the promotion of inclusive PE is positioned as a means improving the quality of life of students with disabilities, ensuring their inclusion and physical rehabilitation (Hutzler, & Levi, 2008; Pellerin, Wilson, & Haegele, 2022).

Our research is based on the need to monitor the level of development of basic physical qualities during inclusive PE, which is the basis for further planning of this process (Blavt, Iedynak, Pereverzieva, Holub, & Melnyk, 2023; Neto, Steenbergen, Wilson, Zamunér, & Tudella, 2020; Pellerin, Wilson, & Haegele, 2022).

Globalization and the advancement of new electronics increase the possibilities for objectivity and validity of test administration in PE (Gupta, 2021; Blavt, Iedynak, Pityn, Hluhov, Guska, Stadnyk, Zaikin, & Karatnyk, 2022). We will agree with our research that the use of the latest electronic technology in the data collection process eliminates the influence of the human factor on the results of the experiment (Gogoi, 2019; Hoenig, Amis, Edmonds, Morgan, Landerman, & Caves, 2018). This circumstance confirms the research data (Desrosiers, Rochette, & Corriveau, 2005; Chaabouni, Methnani, Al Hadabi, Al Busafi, Al Kitani, Al

Jadidi, Samozino, Moalla, & Gmada, 2022) regarding the inadmissibility of interpreting the materials obtained as a result of the experiment, which are obtained by tests with a low level of authenticity. The greater the influence of the human factor on the conduct of the experiment, the more difficult it is to judge to what extent the obtained results depend on the influence of external conditions and side factors (Rum et al., 2021; Mykytyuk, Blavt, Hnatchuk, Stechkevych, & Helzhynska, 2022).

The novelty of the implemented research is that for many years scientists have proposed foot-tapping testing to determine the capabilities of the neuromuscular system of the lower extremities in a medical context. Attempts were also made to use sensors to automate the used test, in particular inertial sensors (Djurić-Jovičić et al., 2018).

Until now, research on the use of this test in the practice of inclusive PE has not been conducted. The age-specific features of the development of these abilities are also taken into account, which improves again in youth (Ivashchenko, 2020). Given that sensorimotor indicators and general coordination abilities show a closer relationship in male individuals, male individuals were selected for the investigation (Davids, Button, & Bennett, 2008).

The practical value of the conducted research, as an important element of substantiating the significance of developments for the use of the obtained results in the process of inclusive PE, makes it possible to obtain an effect from the implementation, which will be another important step in its development.

## Conclusions

Full-scale aggression on the part of Russia destroyed the normal course of social life and led to the urgent need to activate the institutions of inclusion of students with disabilities in higher education. For students with disabilities, given the limited opportunities for active activities due to the presence of deviations in their state of health, which complicate or make this process impossible, it is possible to ensure the rehabilitation process in order to restore lost functions by means of inclusive PE. The practical application of the inclusive PE device developed based on the latest electronics will allow us to optimize this process on a scientific basis to ensure its effectiveness.

The empirically determined indicators of test authenticity obtained during the experiment using the developed device, the digital values of which correspond to the "high level", ensure the individualization of control of the functional indicators of students with disabilities depending on the degree of disability, while at the same time creating an opportunity to develop their competencies. Our results showed that the obtained reliability coefficient values exceeding 0.9 indicate the high quality of the test. Therefore, the developed device is an acceptable method of controlling the level of coordination of movements of the lower limbs of students with disabilities.

Summing up, we can emphasize that the modern progress in inclusive PE, which is currently observed in Ukraine, allows us to hope that a high-quality inclusive space in higher education will be gradually and carefully created in our country, and its quality will meet the requirements of the continuous innovative process.

## Conflicts of interest

No conflicts of interest exist.

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# ТЕСТОВИЙ КОНТРОЛЬ ІНКЛЮЗИВНОГО ФІЗИЧНОГО ВИХОВАННЯ: ОЦІНЮВАННЯ З ВИКОРИСТАННЯМ НОВІТНЬОЇ ЕЛЕКТРОНІКИ

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

Реферат. Стаття: 7 с., 1 таб., 2 рис., 38 джерел.

**Мета дослідження** полягала у визначенні дієвості розробленого на основі новітньої електроніки пристрою для контролю координації рухів нижніх кінцівок студентів з інвалідністю.

**Матеріал та методи.** До дослідження було залучено 34 студенти з інвалідністю, які на момент початку експерименту мали функціональні розлади нижніх кінцівок внаслідок отриманих травм та отримали дозвіл лікаря на участь в експерименті. Дослідження проведено на теоретичному та емпіричному рівні, використано методи: аналізу, синтезу, систематизації, узагальнення, технічного моделювання, педагогічного тестування та математичної статистики.

**Результати.** У процесі дослідження використано пристрій, який розроблено в рамках проведеного дослідження. Пристрій складається з двох гумових килимків, у яких розмішують ємнісні сенсори наближення. Тестове завдання передбачає реєстрацію кількості торкань гумових килимків за 20 с. Інформація, яка надходить із сенсорів при виконанні студентом тестового завдання, а саме почергового торкання великим пальцем ноги гумових килимків, лінією інфрачервоного зв'язку надходить на мікроконтролер. У розробці використано високопродуктивний мікроконтролер ATmega 328P, який може підтримувати широкий спектр сенсорів та формує інформацію про час та частоту виконання рухів ногами. Сигнали торкання пальцями ніг студентом гумових килимків, отримані ємнісними сенсорами, обробляються мікроконтролером та відображаються на ПК через послідовне підключення та з застосування програмного забезпечення Arduino, що дозволяє зчитувати отриману інформацію виконання рухів. За умовами педагогічного експерименту ми намагалися визначити якість результатів вимірювання. Згідно отриманим числовим показникам, числові значення тестової автентичності отримані традиційним способом фіксації результатів фахівцем, відповідають значенню «низький». Результати розрахунків валідності показали, що кореляція результатів тестових вимірів і результатів оцінювання з використанням розробленого пристрою була оптимальною з коефіцієнтом кореляції більшим за 0,6.

**Висновки.** Важливість високого рівня розвитку координації рухів нижніх кінцівок студентів з інвалідністю визначена необхідністю розвитку цієї якості задля забезпечення ефективності їхньої реабілітації в процесі інклюзивного ФВ. Аналіз отриманого матеріалу дозволяє стверджувати, що застосування у практиці інклюзивного ФВ розробленого на основі новітньої електроніки пристрою дозволить науково-обґрунтовано оптимізувати цей процес задля забезпечення його ефективності.

**Ключові слова:** студенти з інвалідністю, фізичне виховання, тестування, інклюзія, контроль, координація, нижні кінцівки.

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REVIEW ARTICLE

## ANALYSIS OF PENCAK SILAT TECHNIQUES USING A BIOMECHANICAL APPROACH: SYSTEMATIC LITERATURE REVIEW

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### Abstract

**Study purpose.** The purpose of this research is to look into the use of biomechanical analysis in pencak silat martial arts techniques.

**Materials and methods.** The PRISMA standards for systematic reviews and meta-analyses were followed in this review investigation. The study must be published within the prior five years, from January 2019 to July 2023. In the search procedure, the following keywords are used: (1) pencak silat; (2) biomechanical analysis. The search engines SINTA (Science and Technology Index) and Scopus were employed.

**Results.** This evaluation included the results of 10 articles. Six articles looked at combat tactics, two at students and the art of movement, nine articles looked at kick attacks, and one looked at attitudes. Four articles proposed time and speed. Six articles investigated pencak silat motion angles.

**Conclusions.** Time, angle, direction, flexion, extension, rotation, adduction, visual focus, force, moment of inertia, rotational kinetic energy, and effort are all inferred factors for pencak silat techniques.

**Keywords:** biomechanical analysis, technique, pencak silat.

### Introduction

Every element of the human body is utilized in the unique movements of pencak silat. Pencak silat training involves physical and mental training, aimed at developing an individual's abilities, strengths, and weaknesses. It also focuses on cultivating noble character and self-reflection through rituals such as breathing exercises and fasting (Ediyono et al., 2023). Additionally, research on the physical demands of pencak silat competition shows that it is characterized by full-body contact combat, indicating the involvement of various parts of the body in the sport (Nurul Khotimah et al., 2022). Furthermore, the development of training models for children in pencak silat emphasizes the importance of adapting movements with biomotor components, indicating the involvement of different body elements in the training

process (Subekti et al., 2021). Therefore, it can be concluded that pencak silat utilizes every element of the human body in its movements.

A systematic literature review is a method used to analyze, synthesize, and summarize existing literature on a particular topic (Dwidienawati et al., 2023). It involves a rigorous and systematic approach to collecting and analyzing data from relevant sources (Moher, Shamseer, et al., 2016). The goal of a systematic literature review is to provide a clear and objective summary of the current state of knowledge on a particular topic, identify gaps in the literature, and suggest areas for future research (Pinto et al., 2023). It is widely used in various fields, including health care, education, psychology, social sciences, and business and management (Amjad et al., 2023).

Biomechanics is a scientific discipline that analyzes movement and studies forms and patterns of movement using mechanical concepts. This is supported by the sciences of anatomy, physiology, and physics, which provide the basis for biomechanics (Syaukani et al., 2023). Despite the complexity of the human body, biomechanics primarily

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focuses on mechanical concepts (H. Wang et al., 2022; Y. Wang et al., 2022; Y. P. Q. W. C. Z. M. W. Y. Wang, 2022). It examines the different ways people move during exercise to better understand movement.

The correctness of sports movements is important because it can have an impact on the success of rehabilitation and injury prevention in athletes (Dirette, 2016). Insufficient movement quality can lead to further damage or re-injury even after successful rehabilitation (Wilke et al., 2017). Objective methods such as biomechanical analysis are seen as the international gold standard for assessing movement quality, but they are not always practical for daily exercise routines (Seuter et al., 2020). Subjective test protocols exist to assess movement quality, but currently do not have sufficient validity. However, there are few practical approaches to assess movement quality after injury (Wren et al., 2020). It is important to identify risk factors and perform pre-injury assessments of movement quality to improve injury prevention. To correctly carry out the technical phases of pencak silat, it is necessary to periodically correct the movements to be more mechanically correct, with more effectiveness and efficiency, and to minimize movement errors (Haqiyah et al., 2020). Understanding biomechanics can help improve mobility and minimize the risk of injury during physical activity (Wu et al., 2023).

There has been a lot of research carried out in the past which has produced pencak silat learning media, including: videos (Sasmitha et al., 2020), Android applications (Marwan, 2018), multimedia (Mardius et al., 2023), mobile applications based on Augmented reality (Muktiani et al., 2022), and training models (Hadiana et al., 2022; Subardi et al., 2021).

In the study of pencak silat martial arts, biomechanical analysis is crucial. This aids in comprehending the stresses and torques produced by a specific strategy. This approach sheds light on variables like knee extension angle and calf length that affect the moment of force. Researchers can ascertain the effects of these strategies on kick speed and moment of inertia by examining the biomechanics of pencak silat techniques. Additionally, biomechanical study can aid in the creation of certain fighting tactics and methods. Additionally, it can assist in creating training plans that fit the physical requirements of the sport. To enhance performance and maximize training methods, biomechanical research in pencak silat fighting is therefore crucial. The application of biomechanical analysis of pencak silat techniques is the goal of this study, according to the researchers, who have based their decision on the aforementioned. Researchers hope that the findings of this study will offer recommendations for how to analyze the biomechanics of the pencak silat technique so that they may build a solid foundation for their work.

## Materials and methods

### Study participants

The words "Analysis biomechanic" and "Martial Arts or Pencak Silat" were searched for in published articles from the Sinta (Science and Technology Index) and Scopus Collection (Science Citation Index Expanded; Social Science Citation Index; Arts & Humanities Science Citation Index) from the years 2019 through 2023.

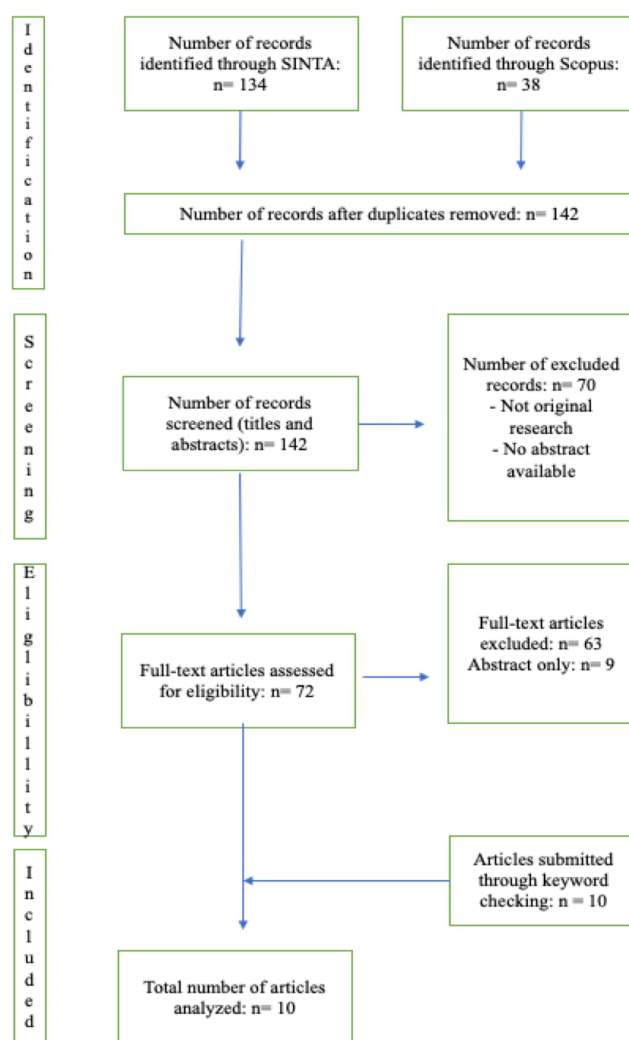


Fig. 1. Flow diagram used to select articles

As shown in the flow diagram (Figure 1), a total sample of 10 articles was obtained from a total of 142 articles by adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher, Stewart, et al., 2016) during the phases of identification, screening, suitability, and inclusion.

The following variables were taken into account in the bibliometric analysis: (a) The annual trend of articles published between 2019 and 2023; (b) the distribution of publications at the institution of the first author; (c) the number of authors; (d) the subject area (training, health, management, education, other, or mixed); (e) the type of study (experimental, descriptive, correlational, other); and (f) the average number of citations per article.

### Study organization

The following variables were taken into account in the literature review: (a) The annual trend of articles published between 2019 and 2023; (b) the distribution of publications at the institution of the first author; (c) the number of authors; (d) the subject area (training, health, management, education, other, or mixed); (e) the type of

study (experimental, descriptive, correlational, other); and (f) the average number of citations per article.

### Statistical analysis

Article titles, abstracts, and keywords were focused as these were sufficient to produce a reliable and sufficient core of articles for further use and analysis. Only open access articles were included in this review study because the authors of this review did not wish to exclude anyone who did not have access to their research. The following inclusion and exclusion criteria were deployed to derive only relevant studies dealing exclusively with a particular topic.

### Results

The table below shows the total number of publications during the selected time period. Year of publication.

**Table 1.** Evolution of the number of publication per year

| Year of publication | Number of articles | Percentage |
|---------------------|--------------------|------------|
| 2019                | 132                | 23%        |
| 2020                | 27                 | 19%        |
| 2021                | 26                 | 18%        |
| 2022                | 34                 | 24%        |
| 2023                | 23                 | 16%        |
| Total               | 142                | 100%       |

Various time periods can be seen in the evolution of the number of publications, as depicted in Figure 2. First, there has been a noticeable rise in scientific output from 2019 (19 articles), 2020 (27 articles), 2021 (16 articles), 2022 (29 articles), 2023 (23 articles).

According to the literature, biomechanical analysis that can be applied in pencak silat techniques is shown in the table

**Table 2.** Summary table of studies

| Topic                                                                          | Sample                 | Result                                                                                                | Source                             |
|--------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------|
| Motion Analysis of the Front Kick                                              | Fighter athletes       | Angles                                                                                                | (Hariono et al., 2021)             |
| Pencak silat combat time motion analysis                                       | Fighter athletes       | Time                                                                                                  | (Subekti et al., 2021)             |
| Pencak Silat Side Kick                                                         | Fighter athletes       | Direction, flexion, extension, rotation, adduction, visual focus.                                     | (Irawan et al., 2021)              |
| Biomechanical Analysis of Horse Kick Athletes Single Art Category Pencak Silat | Athletes single art    | Angles of flexion and extension                                                                       | (Risa Billah & Awang Irawan, 2022) |
| Biomechanical analysis enhance the learning outcomes of Pencak Silat           | Undergraduate students | Angles                                                                                                | (Lubis et al., 2022)               |
| Biomechanics analysis on Jejag kick                                            | Fighter athletes       | The magnitude of the moment of force, moment of inertia, rotational kinetic energy, effort, and power | (Doewes et al., 2022)              |
| Movement Compatibility Analysis of Side Kick                                   | Fighter athletes       | Time and angle                                                                                        | (Syaifullah & Doewes, 2020)        |
| Analysis Of Round House Kick                                                   | Fighter athletes       | Angles                                                                                                | (Sonia and Bhanu Pratap, 2023)     |
| Biomechanical Analysis of Martial Arts Fore Kick                               | Fighter athletes       | Time, speed, flexion angle and extension angle                                                        | (Yan et al., 2022)                 |

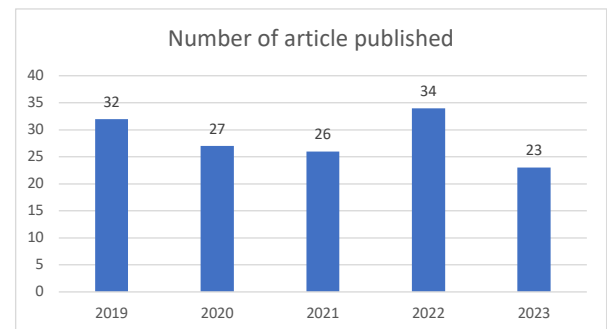


**Fig. 2.** Evolution of the number of publications per year

above. This review comprised ten studies. In eight studies, combat techniques were discussed, as were art trends and pupils. 9 research looked at kick assaults, whereas 1 looked at postures. Four research point to time and speed. Angles in pencak silat movements are suggested by six research. Others propose flexion, extension, rotation, adduction, and visual attention. Moment of force, moment of inertia, rotating kinetic energy, effort, and power are all measured in magnitude.

### Discussion

Pencak silat techniques encompass numerous and distinct pencak silat techniques, as well as their distinct qualities, functions, and performance, as well as theories and strategies for their execution, which are divided into four components: postures, movements, attacks, and defenses. The primary goal of teaching pencak silat is to develop martial arts practitioners who understand the structure of pencak silat techniques and processes (management), as well as tips on how to perform them practically, pragmatically, effectively, efficiently, creatively, tactically, and productively, all of which can create a competitive advantage.

Pencak silat techniques generally use punches, kicks, locks, blocks, and evasion. Each technique is still broken

down again, for example punches are divided into palm punches, backhand punches, scratches, plugs, and so on (Vai et al., 2023; Widiastuti et al., 2022). In addition, in pencak silat, traditional weapons such as swords, machetes, sticks, spears, celurit, knives, tridents, kerambit (a type of knife), keris, and others are taught. Pencak Silat in the psychomotor domain is inseparable from biomechanics, understanding the factors that govern human movement is very important for technique (Ihsan et al., 2022; Kusuma & Novita, 2023; Muzakki et al., 2023). Harnessing biomechanics for training enables intelligent training planning so you can get the most out of it in the shortest time and in the safest way.

The study of exercise biomechanics enables the user to comprehend how the body reacts to various forms of exercise intensity, angle, and posture. In other words, studying exercise biomechanics magnifies these impacts, allowing players to select the best sport for them. Biomechanical analysis can throw light on the facts and help understand what pressures poor technique is exerting on joints and surrounding tissues when form and technique are poor. Athletes of all ages and abilities can benefit from biomechanical analysis, whether to ease discomfort or improve performance. In brief, these are some of the biomechanical advantages: improving movement speed, improving strength, and assisting in the elimination of muscular imbalances. reduced wear and tear on joints and ligaments, better sport-specific form and technique.

Biomechanics is a scientific discipline that integrates factors that affect human movement, drawn from basic knowledge such as physics, mathematics, chemistry, physiology, anatomy and engineering concepts to analyze the forces that occur in the body. forces and moments imposed on workers so that work accidents do not occur. Biomechanics is a scientific discipline that applies mechanical principles to understand performance systems in the human body (Keogh, 2021; Norman et al., 2021; Y. Wang, 2022). It focuses on the study of movement in living organisms, including the interaction of forces, moments, and mechanical properties on the movement or balance of body segments. Biomechanics also examines the mechanical behavior of biological systems and subsystems, such as the musculoskeletal system and its ligaments and tendons (Bandeiras, 2019; Bavi et al., 2022; Papageorgiou, 2020).

Biomechanics knowledge is critical to engineering education, particularly for those working in the biomedical sector, because it permits the development of equipment such as prosthetics and rehabilitation tools that promote healing, restoration, and simulate lost biological capabilities. Overall, biomechanics is a subfield of biophysics that studies the structure, function, and movement of living organisms. Biomechanics is a science that combines physics (particularly mechanics) and engineering, as well as knowledge of the work environment. General biomechanics is the branch of biomechanics that studies the fundamental laws that govern the organic human body at rest and in motion. Biomechanics is a study that specializes in analyzing segments of human body motion, one of which is quantitative data on angles in degrees (Hughes et al., 2021).

There are two major benefits to studying the effects of these factors. For starters, it enables training to enhance technique while avoiding harm. This research also aids in the enhancement of performance and physical fitness in terms of strength, cardiovascular fitness, and flexibility. There

are numerous advantages to doing biomechanical analysis, because biomechanics gives a wealth of information for various types of human movement analysis, particularly to improve athlete performance (increase performance) and lower the risk of injury (Teferi & Endalew, 2020).

## Conclusions

Based on the outcomes of using techniques for biomechanical analysis of pencak silat by searching literature related to the analysis of pencak silat biomechanics, it can be concluded that the biomechanical analysis that can be applied to pencak silat techniques is time, angles, direction, flexion, extension, rotation, adduction, visual focus, force, moment of inertia, rotational kinetic energy, effort.

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## Conflict of interest

The authors reported no potential conflicts of interest.

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## АНАЛІЗ ТЕХНІК ПЕНЧАК-СИЛАТУ З ВИКОРИСТАННЯМ БІОМЕХАНІЧНОГО ПІДХОДУ: СИСТЕМАТИЧНИЙ ОГЛЯД ЛІТЕРАТУРИ

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

Реферат. Стаття: 7 с., 2 табл., 2 рис., 44 джерела.

**Мета дослідження.** Метою цього дослідження є вивчення використання біомеханічного аналізу в техніках бойових мистецтв пенчак-силату.

**Матеріали та методи.** У цьому оглядовому дослідженні дотримувалися стандартів PRISMA, передбачених для систематичних оглядів і метааналізів. Дослідження повинно було бути опубліковане упродовж попередніх п'яти років, із січня 2019 року до липня 2023 року. У процедурі пошуку використовувалися такі ключові слова: (1) пенчак-силат; (2) біомеханічний аналіз. У дослідженні використовували пошукові системи SINTA (Science and Technology Index – «Науково-технологічний індекс») та Scopus.

**Результати.** Ця оцінка включала результати 10 статей. У шести статтях розглядали тактику бою, у двох – учнів і мистецтво пересування, у дев'яти статтях розглядали атаки ударами ніг, а в одній – ставлення. У чотирьох статтях пропонували до уваги час і швидкість. У шести статтях досліджували кути руху в пенчак-силаті.

**Висновки.** Час, кут, напрямок, згинання, розгинання, обертання, приведення, зоровий фокус, сила, момент інерції, кінетична енергія обертання та зусилля – це всі одержані як висновок фактори для технік пенчак-силату.

**Ключові слова:** біомеханічний аналіз, техніка, пенчак-силат.

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REVIEW ARTICLE

## ANTIOXIDANT AND ANTI-INFLAMMATORY PROPERTIES OF BEE PRODUCTS POTENTIALLY REDUCE OXIDATIVE STRESS AND INFLAMMATION AFTER PHYSICAL ACTIVITY/EXERCISE: A SYSTEMATIC REVIEW

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### Abstract

**Study purpose.** This research aims to analyze and highlight the potential of bee products in reducing oxidative stress and inflammation after physical activity/exercise.

**Materials and methods.** This research uses a systematic review method by searching various journal databases such as Scopus, Web of Science, PubMed and Embase. The inclusion criteria in this study were articles published in the last 5 years and articles discussing bee products, honey, oxidative stress, inflammation, physical activity, and exercise. The exclusion criteria in this study were articles published in disreputable journals. Titles, abstracts, and full texts of articles were screened then verified and stored in Mendeley software. A total of 7,124 articles from the Scopus, Web of Science, PubMed and Embase databases were identified. A total of 8 articles that met the inclusion criteria were selected and analyzed for this systematic review.

**Results.** Bee products that have anti-oxidant properties can reduce oxidative stress and the anti-inflammatory properties of bee products can reduce uncontrolled inflammation due to exercise.

**Conclusions.** Bee products contain flavonoids which have anti-oxidant properties which can reduce oxidative stress. In addition, the anti-inflammatory properties of bee products can reduce uncontrolled inflammation due to physical activity/exercise. In this case, honey works by inhibiting inflammation through NF-κB signals and reducing inflammation by suppressing the secretion of pro-inflammatory cytokines such as TNF-α and inflammatory markers such as CRP. Reducing inflammation can reduce the intensity of muscle pain. It is recommended that bee products be used in individuals to reduce oxidative stress and inflammation after physical activity/exercise.

**Keywords:** bee products, oxidative stress, inflammation, physical training, healthy lifestyle.

### Introduction

Regular physical activity/exercise can improve health and fitness (Rueggsegger & Booth, 2018). However, on the other hand, intense physical activity/exercise will trigger

uncontrolled oxidative stress due to an imbalance between reactive oxygen species (ROS) and antioxidants (Thirupathi et al., 2021). Increased ROS can cause degenerative diseases such as cancer, cell damage and type 1 diabetes (Darenskaya et al., 2021). In addition, physical activity/exercise at high intensity, especially with eccentric movements, causes metabolic stress in the form of energy deficiency and muscle damage (Harty et al., 2019). Muscle damage caused by exercise is characterized by the onset of muscle pain (Casanova et al., 2018). Thus, the resulting muscle pain

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can limit performance after a training session (Owens et al., 2019; Romero-Parra et al., 2021; Viribay et al., 2020; Xin & Eshaghi, 2021). Several studies explain that pain occurs due to an uncontrolled inflammatory process due to increased levels of Tumor Necrosis Factor-Alpha (TNF- $\alpha$ ) and Interleukin 6 (IL-6) levels during exercise-induced muscle damage (Dupuy et al., 2018). Meanwhile, Creatine Kinase (CK) is believed to be a biomarker for muscle damage (Esteves-Lima et al., 2020; Oosthuysen & Bosch, 2017).

In most cases, inflammation peaks 1 to 2 days after an exercise session (Chang et al., 2021; Hung et al., 2021; Muljadi et al., 2021). The current phenomenon is that around 30 million people worldwide who experience pain are usually treated with non-steroidal anti-inflammatory drugs (NSAIDs) (Ayubi & Sastika Putri, 2021; Kyriakidou et al., 2021). Giving NSAIDs after exercise is a wrong alternative for managing pain, this is because NSAIDs have a disruptive effect on the muscle growth response which has an impact on hypertrophy and muscle strength. As a result, giving NSAIDs will actually negate the results of the exercise carried out (Schoenfeld, 2012).

Alternative solutions need to be sought to overcome this problem. One of the natural products produced by bees is honey. Apart from honey, bees also produce many by-products such as pollen, propolis and royal jelly (Ali & Kunugi, 2020). Several studies report that bee product has anti-inflammatory properties (Esa et al., 2022; Eteraf-Oskouei et al., 2020). In this regard, anti-inflammatory cytokines such as interleukin 10 (IL-10) play an important role in controlling the inflammatory response. (Srivastava et al., 2017). Apart from that, bee products is also famous for its anti-oxidants (Cianciosi et al., 2018). On the other hand, honey plays a role in suppressing pro-oxidant activity by increasing the heme oxygenase 1 (HO-1) and glutathione peroxidase (GPx) genes. (Iova et al., 2021). Bee products has also been used in the world of medicine and health to speed up wound healing (Cianciosi et al., 2018). In this case, the many benefits of bee products give us the

opportunity to relate and discuss in depth the effects of bee products in reducing oxidative stress and uncontrolled inflammation after physical activity/exercise through a systematic review.

This research aims to analyze and highlight the potential of bee products in reducing oxidative stress and inflammation after physical activity/exercise.

## Materials and methods

### Studi design

This research uses a systematic review method by searching various journal databases such as Scopus, Web of Science, Pubmed and Embase.

### Eligibility criteria

The inclusion criteria in this study were articles published within the last 5 years. The next article discusses bee products, honey, oxidative stress, inflammation, physical activity, and exercise. The exclusion criteria in this study were articles published in national and non-reputable journals.

### Procedure

Titles, abstracts and full texts of articles were screened then verified and stored in Mendeley software. In the first stage, 7,124 articles from the Scopus, Web of Science Pubmed and Embase databases were identified. Next, in the second stage, 55 articles were screened based on the suitability of the title and abstract. In the third stage, 31 articles were verified for further processing. At this stage we filter based on the suitability of the full article. Next, in the final stage, 8 articles that met the inclusion criteria were selected and analyzed for this systematic review. For standard operations, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) assessment.

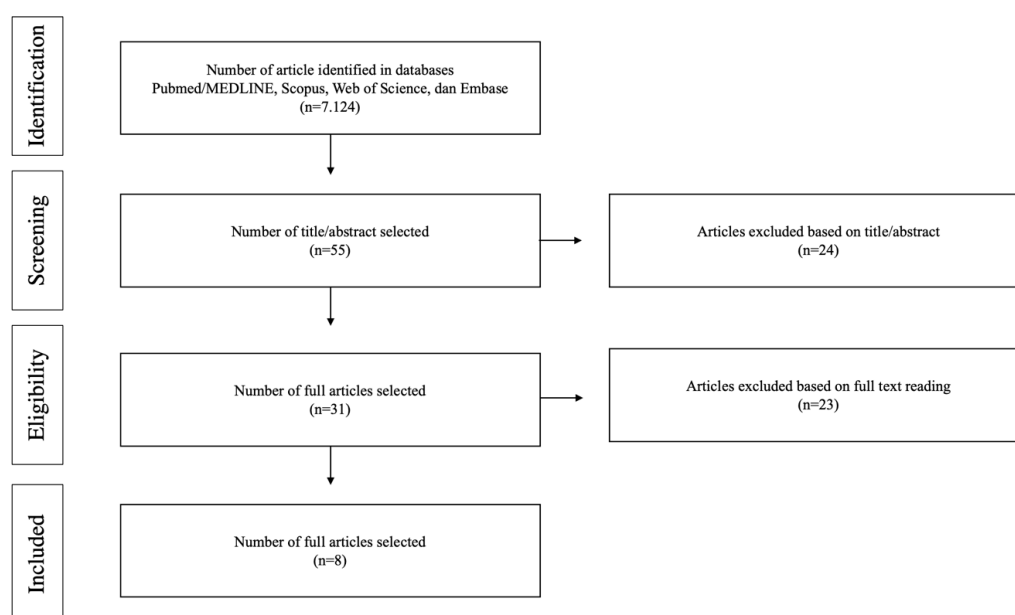


Fig. 1. PRISMA flowchart of the article selection process

## Results

**Table 1.** Results of a review of the effects of bee products on oxidative stress and inflammation

| Author                      | Sample Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                            | Study Design      | Intervention                                                                                                                                                                                                                          | Results                                                                                                                                                                                                               |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (Kheirdeh et al., 2022)     | 56 female mice aged 8-10 weeks, weighing 200-220 g, were divided into 8 groups, namely healthy control group, experimental autoimmune encephalomyelitis group, sham group, royal jelly group with a honey base dose of 50mg/kg, royal jelly group with a base ingredient honey dose 100mg/kg, sports training group + royal jelly with a honey-based ingredient dose 50mg/kg and sports training group + royal jelly with a honey-based ingredient dose 100mg/kg. | Experimental      | Providing royal jelly intervention with honey as the base ingredient. Intervention was carried out every day for 5 weeks. Training consists of treadmill training every session of 5 to 25 minutes at a speed of 6m/s 5 times a week. | Royal jelly consumed at a dose of 50 mg/kg and 100 mg/kg together with aerobic exercise has benefits on pain threshold.                                                                                               |
| (Petelin et al., 2019)      | A total of 72 overweight people aged 25 years were divided randomly into 2 groups, namely the control group and the treatment group with bee product in the form of royal jelly.                                                                                                                                                                                                                                                                                  | Experimental      | Bee product in the form of royal jelly with a dose of 333 mg/capsule                                                                                                                                                                  | Providing bee product interventions such as royal jelly has the potential to provide benefits on lipid profiles, inflammation, oxidative stress, mood and satiety in overweight people.                               |
| (Ali et al., 2021)          | 8 relevant studies on honey, fatigue, physical performance, inflammation and exercise during COVID-19                                                                                                                                                                                                                                                                                                                                                             | Literature Review | Giving bee products such as royal jelly, propolis and bee pollen.                                                                                                                                                                     | This literature study reports that bee products such as royal jelly, propolis and bee pollen have the potential to improve physical performance, speed recovery and reduce the inflammatory response during COVID-19. |
| (Ranneh et al., 2021)       | 42 rats weighing 250-270 g received 4.6 and 9.2 g/kg bee honey for 7 days followed by lipopolysaccharide induction and blood samples were taken 6 hours later.                                                                                                                                                                                                                                                                                                    | Experimental      | Bee honey is given at doses of 4.6 and 9.2 g/kg                                                                                                                                                                                       | Bee honey is able to reduce the production of reactive oxygen species (ROS), lipid peroxidation, reduce NF-kB signals and pro-inflammatory cytokines.                                                                 |
| (Tavafzadeh et al., 2023)   | 48 young women aged 19-25 years were divided into 4 groups, namely the 16 weeks sedentary activity group, the 8 weeks exercise group followed by 8 weeks sedentary activities, the 8 weeks honey supplementation group followed by 8 weeks sedentary activities group, and the 8 weeks combination exercise and honey supplementation group. followed by 8 weeks of sedentary activity.                                                                           | Experimental      | Honey supplementation was given in a dose of 20 g and dissolved in 300 mL water. The aerobic exercise used is dance training.                                                                                                         | The combination of honey supplementation and dance training can effectively maintain bone health and antioxidant status triggered by exercise                                                                         |
| (Stavropoulou et al., 2022) | Eight-week-old female C57BL/6 mice were lipopolysaccharide induced and monitored for 4 hours.                                                                                                                                                                                                                                                                                                                                                                     | Experimental      | Honey intervention was given 30 minutes before lipopolysaccharide injection.                                                                                                                                                          | The anti-inflammatory properties of honey are able to strongly suppress serum TNF-a levels in mice that experience inflammation due to lipopolysaccharide induction.                                                  |

**Table 1** (continued)

| Author                     | Sample Characteristics                                                                                                                                                                                                                                        | Study Design | Intervention                                                                                                                                                                                                                                                                                               | Results                                                                                                                                                       |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (Ovchinnikov et al., 2022) | 20 healthy swimmers with an average age of 19 years and male were divided into 2 groups, namely the placebo group and the group given bee products supplementation in the form of royal jelly.                                                                | Experimental | Bee products intervention in the form of royal jelly supplementation was given at a dose of 400 mg once a day for 10 days. Before being given intervention, swimmers did HIIE training, which was done in 4 sets over a distance of 50 meters with maximum speed and recovery between sets for 45 seconds. | Bee products intervention in the form of royal jelly for 10 days has the potential to speed up recovery from muscle damage and reduce oxidative stress.       |
| (Noura et al., n.d.)       | 24 mice aged an average of 8 weeks were injected with 8 mg/kg trimethyltin. Next, the mice were divided into 4 groups, namely the resistance training group, the resistance training group + royal jelly group, the royal jelly group, and the control group. | Experimental | Endurance training in the form of treadmill training at a speed of 15-20m/minute, 5 sessions per week for 8 weeks. Royal jelly is given at a dose of 100 mg/kg every day.                                                                                                                                  | Endurance training and royal jelly were able to significantly reduce the expression of inflammatory markers such as the biomarker CRP in mouse muscle tissue. |

## Discussions

The main research objective of this systematic review is to analyze and highlight the potential of bee products in reducing inflammation and oxidative stress after physical activity/exercise. Bee products contain flavonoids which have antioxidant properties. The chemical structure of bee products can be seen in Figure 2 (Silva et al., 2021). It is known that physical activity increases the production of Reactive Protein Species (ROS) (Thirupathi et al., 2021). Excessive increase in ROS production can cause damage to muscle fibers which will later lead to fatigue (Wang et al., 2021). On the other hand, the presence of a small stimulus from a low increase in ROS production can express

endogenous antioxidants (Eddaikra & Eddaikra, 2021; Simioni et al., 2018). However, if physical activity is carried out intensely, it will cause an imbalance between excessive ROS production and the oxidant defense system, called oxidative stress (Hajam et al., 2022).

The idea that bee products contain antioxidant properties is supported by a study conducted on mice reporting that honey intervention at doses of 4.6 and 9.2 g/kg for 7 days followed by lipopolysaccharide induction had the potential to reduce the production of reactive oxygen species (ROS) (Ranneh et al., 2021). In addition, a study conducted on young women reported that honey supplementation given at a dose of 20 g and dissolved in 300 mL water during aerobic exercise was effectively able to maintain bone health

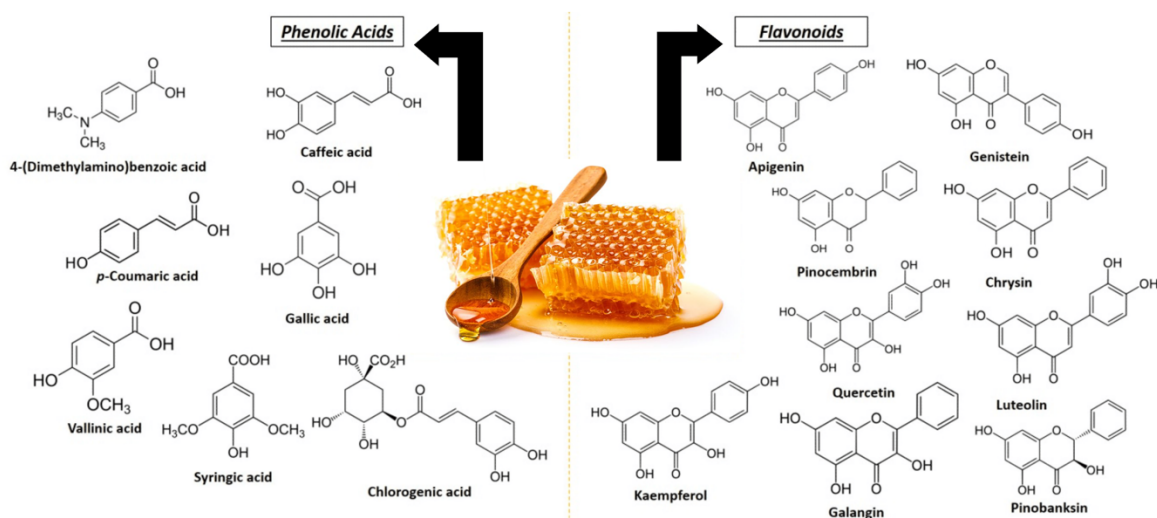


**Fig. 2.** Chemical structure of bee products

and antioxidant status triggered by exercise (Tavafzadeh et al., 2023). Furthermore, the results of this study were strengthened by research which reported that swimmers who were given bee product intervention in the form of royal jelly supplementation at a dose of 400 mg for 10 days had the potential to reduce oxidative stress and speed up recovery after training (Ovchinnikov et al., 2022). Physiologically, an interesting thing is that the flavonoids contained in honey work by increasing mitochondrial calcium ions ( $\text{Ca}^{2+}$ ) in cells, causing hyperpolarization of cell membranes. So increasing mitochondrial  $\text{Ca}^{2+}$  has the potential to reduce oxidative stress (Overdevest et al., 2018).

Furthermore, one of the main sources of oxidative stress is the immune system, and inflammation is the main reaction of the immune system to restore cells damaged by intense exercise back to normal (Simioni et al., 2018). Indeed, when the cells of an organ are damaged, the immune system becomes active (Marshall et al., 2018). The cells will stimulate macrophages to increase the production of pro-inflammatory and anti-inflammatory cytokines (Ayubi et al., 2022). It has been reported that TNF- $\alpha$  is one of the pro-inflammatory cytokines that trigger muscle pain (Fernández-Lázaro et al., 2020; Nanavati et al., 2022). In this regard, bee products, which has anti-inflammatory properties, can be an intervention strategy in controlling uncontrolled inflammatory processes due to exercise. A study conducted on mice reported that Royal jelly consumed at a dose of 50 mg/kg and 100 mg/kg along with aerobic exercise had benefits on pain threshold (Kheirdeh et al., 2022). The results of this research were reinforced by a study which reported that the anti-inflammatory properties of bee products were able to strongly suppress serum TNF- $\alpha$  levels in mice experiencing inflammation due to lipopolysaccharide induction (Stavropoulou et al., 2022). In this regard, a study on mice also reported that resistance training in the form of treadmill training for 15-20 minutes, 5 sessions/week carried out for 8 weeks and administration of royal jelly was able to significantly reduce the expression of inflammatory markers

such as the biomarker CRP in mouse muscle tissue (Noura et al., n.d.). Furthermore, a study in mice also reported that bee honey intervention given at doses of 4.6 and 9.2 g/kg to mice induced by lipopolysaccharide was able to reduce NF- $\kappa\text{B}$  signals and pro-inflammatory cytokines (Ranneh et al., 2021). Regarding NF- $\kappa\text{B}$  signaling, NF- $\kappa\text{B}$  is initially active when tissue damage occurs and then plays an important role in mediating inflammation, especially the secretion of pro-inflammatory cytokines such as TNF- $\alpha$  (Acar et al., 2018). So if NF- $\kappa\text{B}$  signaling is inhibited using bee products, it will also affect pro-inflammatory cytokines and reduce muscle pain. Recent literature studies during COVID-19 report that bee products and exercise have the potential to improve physical performance, speed recovery and reduce the inflammatory response during COVID-19 (Ali et al., 2021). Furthermore, a study on overweight people reported that providing bee products supplementation interventions in the form of royal jelly had the potential to benefit lipid profiles, inflammation, oxidative stress, mood and satiety in overweight people (Petelin et al., 2019).

So, bee products which has anti-oxidant properties can reduce oxidative stress and the anti-inflammatory properties of honey can reduce uncontrolled inflammation due to exercise. Furthermore, for more details regarding the benefits of honey in reducing oxidative stress and inflammation, see Figure 3.

## Conclusions

Bee products contain flavonoids which have anti-oxidant properties which can reduce oxidative stress. In addition, the anti-inflammatory properties of bee products can reduce uncontrolled inflammation due to physical activity/exercise. In this case, honey works by inhibiting inflammation through NF- $\kappa\text{B}$  signals and reducing inflammation by suppressing the secretion of pro-inflammatory cytokines such as TNF- $\alpha$  and inflammatory markers such as CRP. Reducing inflammation can reduce the intensity of muscle pain. It is recommended

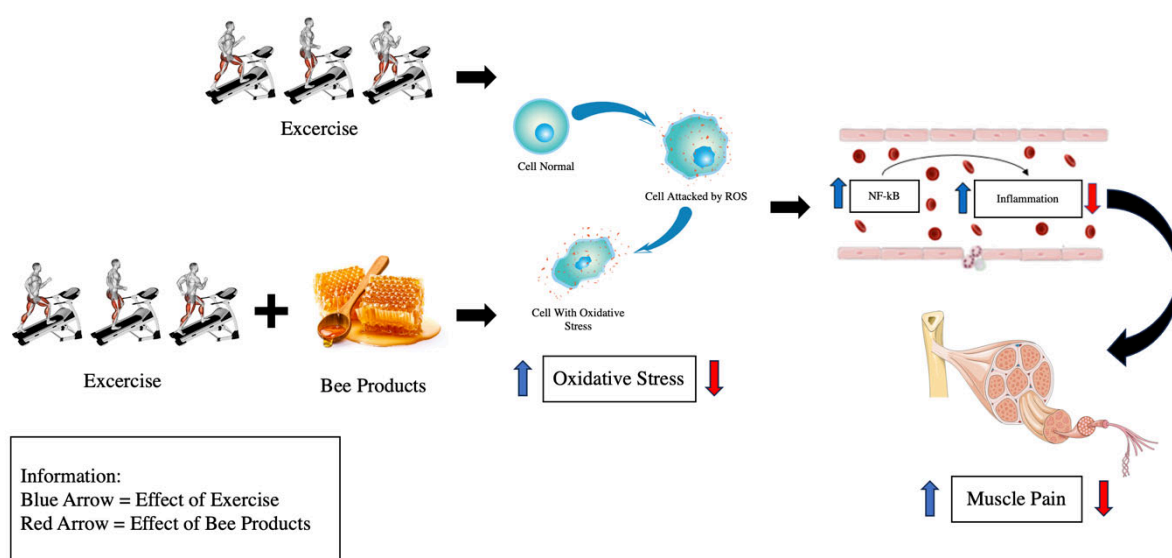


Fig. 3. Mechanism of action of bee products to reduce oxidative stress and inflammation

that bee products be used in individuals to reduce oxidative stress and inflammation after physical activity/exercise

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## Conflicts of Interest

The authors declare no conflict of interest

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## АНТИОКСИДАНТНІ ТА ПРОТИЗАПАЛЬНІ ВЛАСТИВОСТІ ПРОДУКТІВ БДЖІЛЬНИЦТВА ПОТЕНЦІЙНО ЗМЕНШУЮТЬ ОКСИДАТИВНИЙ СТРЕС І ЗАПАЛЕННЯ ПІСЛЯ ФІЗИЧНОЇ АКТИВНОСТІ/ВПРАВ: СИСТЕМАТИЧНИЙ ОГЛЯД

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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., 43 джерела.

**Мета дослідження.** Метою цього дослідження було проаналізувати та підкреслити потенціал продуктів бджільництва до зменшення оксидативного стресу та запалення після фізичної активності/вправ.

**Матеріали та методи.** У цьому дослідженні використовують метод систематичного огляду шляхом пошуку в різних базах даних журналів, таких як Scopus, Web of Science, PubMed та Embase. Критеріями включення в цьому дослідженні були статті, опубліковані за останні 5 років, і статті, у яких обговорювали продукти бджільництва, мед, оксидативний стрес, запалення, фізичну активність і вправи. Критеріями виключення в цьому дослідженні були статті, опубліковані в журналах із сумнівною репутацією. Назви, анотації та повні тексти статей ретельно відбирали, перевіряли та зберігали в програмному забезпеченні Mendeley. Загалом було визначено 7124 статті з баз даних Scopus, Web of Science, PubMed та Embase. Загалом для цього систематичного огляду було відібрано та проаналізовано 8 статей, які відповідали критеріям включення.

**Результати.** Продукти бджільництва, які мають антиоксидантні властивості, можуть зменшувати оксидативний стрес, а протизапальні властивості продуктів бджільництва можуть зменшувати неконтрольоване запалення, спричинене виконанням фізичних вправ.

**Висновки.** Продукти бджільництва містять флавоноїди, які мають антиоксидантні властивості, що можуть зменшувати оксидативний стрес. Крім того, протизапальні властивості продуктів бджільництва можуть зменшувати неконтрольоване запалення, спричинене фізичною активністю/вправами. У цьому разі мед діє, інгібуючи запалення шляхом активації сигнального шляху NF-κB (ядерний фактор «каппа-бі») і зменшуючи запалення шляхом пригнічення секреції прозапальних цитокінів, таких як TNF-α (фактор некрозу пухлини альфа, ФНП-альфа), і маркерів запалення, таких як CRP (С-реактивний білок). Зменшення запалення може зменшити інтенсивність м'язового болю. Рекомендується використовувати продукти бджільництва для зменшення оксидативного стресу та запалення після фізичної активності/вправ.

**Ключові слова:** продукти бджільництва, оксидативний стрес, запалення, фізична підготовка, здоровий спосіб життя.

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REVIEW ARTICLE

## RESEARCH TRENDS IN FOOTBALL TRAINING FOR YOUNG PLAYERS IN THE LAST 15 YEARS: BIBLIOGRAPHIC ANALYSIS

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### Abstract

**The objective** of this paper is to evaluate the research trends in football training for young players under 18 years old in the last 15 years.

**Materials and methods.** This was a bibliometric analysis and systematic review study. Articles published since 2008 were searched for by the keywords "Football Training" and "Football Exercise" using a comprehensive strategy on SCOPUS research journal databases. There were 1,053 articles with 4802 citations mined on October 17th, 2023. Thereafter, 217 articles were selected for further analysis by using VOS Viewer computer software.

**Results.** The United Kingdom (67), The United States (60), and Spain (41) were the three countries that had the most publications in football training. There were 6 keyword clusters that reflected various research focuses on football training for younger players. Based on the top 10 most cited references in football training for younger players, there were several major themes that covered various aspects of the research trend and development in the last 15 years, i.e. (1) Factors in the Development of Young Football Players, (2) Tactical Analysis and Collective Behavior in Small-Sided Games, (3) Game Intensity and Activity Profile in Young Football Players, (4) Plyometric Training and Its Effects on Preadolescent Players, and (5) Injury Prevention and Neuromuscular Training in Adolescent Football Players.

**Conclusions.** Football research for under-18 players has grown rapidly. This research trend shows that football requires not only physical and technical skills, but also social and mental aspects. Further research can be directed toward understanding and integrating holistic aspects of football coaching, including the development of non-physical skills, such as leadership, teamwork, and conflict resolution. Further investigation into the use of technology in football coaching, such as video analysis, sensor-based performance measurement, and artificial intelligence applications to provide deeper insight into player progress.

**Keywords:** football training, bibliometric, young player, sports science.

### Introduction

One of the most popular sports in the world is football (Hansen et al., 2013). This is due to the dynamic nature of

football, which allows players to switch between defensive and attacking positions (Serghei et al., 2021). Football is a team sport in which participants make physical contact with one another (Mohr et al., 2022). In addition, playing football calls for a variety of athletic abilities (Ramírez-Campillo, Henriquez-Olguín, et al., 2015), mental, tactical, and technical acuity (Ferrete et al., 2014). The process of teaching football is intended to help players improve their technical, physical, tactical, and mental skills (Asadi et al., 2018).

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The cornerstone of the football game is technical ability (Olthof et al., 2015). This covers moves including dribbling, passing, kicking, controlling the ball, and using both feet while playing (Coutinho et al., 2023). It is through systematic and consistent practice that young players are guided to master these abilities (Campolettano et al., 2016). In football, being in good physical shape is crucial (Cvetković et al., 2018). Moreover, strengthening, speed, endurance, flexibility, and coordination can all be achieved through physical exercise (Negra et al., 2017). This aids players in enduring lengthy and difficult battles (Makhlouf et al., 2018).

Coaching football also include studying game strategies (Nakonechnyi et al., 2023). Basic ideas like playing position, team formation, attack, defense, and playing strategy must be understood by players (Bolotin & Bakayev, 2017). This entails being able to read the game and making wise choices (McGuckian et al., 2020). Football is a game where mentality is very crucial (Kozina et al., 2019). Gamers need to develop their ability to regulate their emotions, stay focused, boost their confidence, and handle pressure (Fernandez-Gonzalo et al., 2010). Additionally, coaches can offer guidance on effective communication, motivation, and rebounding from setbacks (Figueres et al., 2014).

Coaching football frequently entails attending games and competitions (Bettega et al., 2023). This allows players to use the abilities and information they acquire in practical settings (Alesi et al., 2015). Additionally beneficial to mental growth and experience coping with game strain is competition (Hendry et al., 2014). Excellent facilities and knowledgeable supporters are essential components of a successful football coaching program (Prasetya & Argantos, 2019).

Coaching football also entails assessing and tracking player development (Deprez et al., 2015). This enables athletes to pinpoint their areas of weakness and establish developmental objectives (Brechtot & Flepp, 2020). In addition to the technical and physical aspects, teaching football ethics is crucial (Práxedes et al., 2016). Fair play, sportsmanship, and consideration for both opponents and teammates are examples of this (Mills et al., 2012). Football coaching is a continuous process that needs the families, coaches, and players to be committed (Eather et al., 2020).

Football players can maximize their abilities and potential through this methodical and thorough technique, propelling them to new heights in the sport (O'Connor et al., 2018). Good football coaching also helps create a strong foundation for the future of the sport of football as a whole (Akenhead & Nassis, 2016). However, football coaching doesn't just apply to elite athletes, it also applies to all age levels and skill levels (Balyi et al., 2013). This means that everyone could thrive in the sport they love. A lot of research related to football training has also been carried out, but the trend for younger players is still not focused and still not contextual enough to be directly implemented by coaches. This bibliometric research aims to see the development of research trends in football training for young players under 18 years of age in the last 15 years with the following research question:

1. To analyze the football training for young players under 18 years old's research trends in the last 15 years.
2. To analyze the countries that contributed to football training for young players under 18 years old's research trends in the last 15 years.

3. To analyze the pattern of keyword clusters in football training for young players under 18 years old's research trends in the last 15 years.
4. To analyze the top 10 cited publications in football training for young players under 18 years old's research trends in the last 15 years.

## Materials and methods

### Materials for analysis

There were 1,053 articles from Scopus that were mined on October 17th, 2023. Therefore, 217 articles were selected for further analysis by using VOS server computer software. There were 10 articles selected as the most cited articles which were selected for this systematic review.

### Organization of the study

This type of research is a Bibliometric Analysis and Systematic Review. Article searches were carried out using a comprehensive strategy on SCOPUS research journal databases. The keywords used are "Football Training", "Football Exercise", and "Football Academy". Furthermore, the exclusion criteria were journals published in the last 15 years from 2023.

### Methods of analysis

For standard operationalization, this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

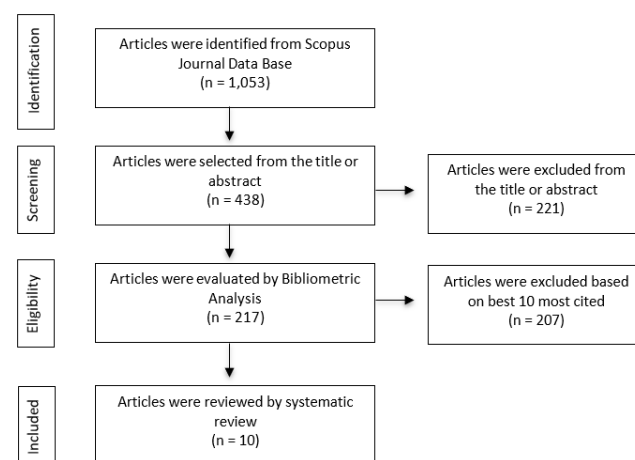


Fig. 1. PRISMA flowchart of the article selection process

## Results

### Research Trend of Football Training for Young players Under 18 Years Old in the Last 15 Years

The research trends of football training for young players under 18 years old in this literature review are presented in Table 1. The number of publications (f) fluctuates from year to year, with notable variations. However, the total number of citations (Total Cited) tends to increase gradually over

**Table 1.** Document of Football Training Research for Young players Under 18 Years Old in the Last 15 Years

| Year  | f   |     | Total Cited |      | Average Cited |       |
|-------|-----|-----|-------------|------|---------------|-------|
| 2008  | 4   |     | 152         |      | 78            |       |
| 2009  | 3   |     | 170         |      | 86.5          |       |
| 2010  | 6   | 21  | 364         | 1313 | 185           | 667   |
| 2011  | 5   |     | 126         |      | 65.5          |       |
| 2012  | 3   |     | 501         |      | 252           |       |
| 2013  | 8   |     | 472         |      | 240           |       |
| 2014  | 7   |     | 319         |      | 163           |       |
| 2015  | 15  | 52  | 527         | 1933 | 271           | 992.5 |
| 2016  | 11  |     | 371         |      | 191           |       |
| 2017  | 11  |     | 244         |      | 127.5         |       |
| 2018  | 21  |     | 445         |      | 233           |       |
| 2019  | 25  |     | 453         |      | 239           |       |
| 2020  | 32  | 144 | 463         | 1556 | 247.5         | 850   |
| 2021  | 33  |     | 163         |      | 98            |       |
| 2022  | 16  |     | 27          |      | 21.5          |       |
| 2023  | 17  |     | 5           |      | 11            |       |
| Total | 217 |     | 4802        |      | 2509.5        |       |

the years, reaching its peak in 2020 with 463 citations. In 2015, there was a substantial increase in the number of publications (15) compared to the previous year. This year also stands out for receiving the highest total citations (527), signifying significant academic recognition.

The average number of citations per publication (Average Cited) showcases substantial variability, indicating the impact and reception of publications in different years. While the number of publications remained relatively consistent from 2016 to 2019, the total number of citations steadily increased, indicating an increasing impact of the work. The average number of citations per publication in 2020 is the greatest (247.50), indicating that the influence and caliber of articles in that year were very notable. In 2021, there was a notable decline in the average number of citations per publication, which deviates significantly from prior trends.

The dataset's lowest average citations per publication occurred in 2022 and 2023 as a result of large increases in both the total number of citations and publications. In conclusion, this table emphasizes how academic research is dynamic and has differing degrees of influence and acknowledgment depending on the year. The average number of citations per publication, total number of citations, and changes in publication numbers offer important insights on how the body of scholarly work in the subject is changing. In this academic setting, it might provide a foundation for additional analysis and research evaluation.

Research conducted between 2008 and 2012 about football training for young players under the age of eighteen (2012) found that a significant portion of the research focused on injury aspects, particularly ligament injuries. In order

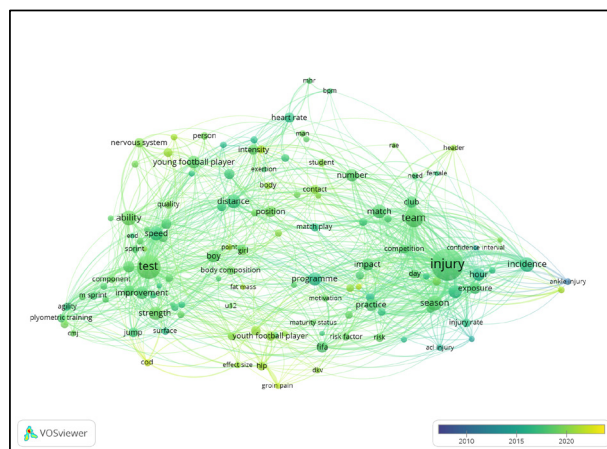


**Fig. 2.** Football Training Research Trends over the Past 15 Years for Young Players

to determine the elements impacting the growth of young football players, Mills et al. (2012) conducted interviews with coaches. They placed a special emphasis on awareness as a fundamental component. Conversely, a cluster randomized controlled trial was carried out by Walden et al. (2012) to assess the efficacy of neuromuscular training in lowering the incidence of knee injuries among female teenage football players. During this time, there was a shift in study focused on figuring out how to lower the risk of injury that young football players suffer in order to enhance their health and playing experience.

Between 2013 and 2017, the focus of research switched to different types of fitness regimens for young players. Studies on plyometric training in preadolescent athletes, including those by Michailidis et al. (2013) and Ramírez-Campillo, Burgos, et al. (2015), demonstrate the considerable performance gains that may be achieved with this kind of training. The need to create training regimens that take into account the developmental traits of young football players is highlighted by the growing body of knowledge regarding the training modalities that are most suitable and advantageous for these players at this age.

From 2018 to 2023, more research will be conducted on the neurological system, physical capabilities, and body composition as supporting factors in performing basic technical training. Studies conducted during this time period, like Kilding et al. (2018), concentrate on the efficacy of training regimens that can aid in the growth of young athletes, not just in terms of fundamental skills but also in bolstering areas such as the neurological system, physical capabilities, and body composition. This study sheds new light on the value of a comprehensive approach to training young football players in order to maximize their development and minimize injuries, laying the groundwork for a successful future in the game.

#### Country Contributed to Football Training Research for Young Players Under 18 Years Old in the Last 15 Years

Table 2 offers a thorough summary of the top 10 nations that, throughout the past 15 years, have significantly advanced the field of football training research for young

**Table 2.** Top 10 Countries Contributed to Football Training Research for Young Players Under 18 Years Old in the Last 15 Years

| Country        | f   | Total Cited | Average Cited |
|----------------|-----|-------------|---------------|
| United Kingdom | 67  | 1596        | 831.50        |
| United States  | 60  | 1220        | 640.00        |
| Spain          | 41  | 852         | 446.50        |
| Australia      | 33  | 579         | 306.00        |
| Germany        | 29  | 626         | 327.50        |
| Italy          | 26  | 417         | 221.50        |
| Switzerland    | 21  | 541         | 281.00        |
| Denmark        | 20  | 550         | 285.00        |
| Portugal       | 19  | 617         | 318.00        |
| Poland         | 18  | 108         | 63.00         |
| Total          | 334 | 7106        | 372.00        |

players under the age of 18. It provides information on the volume and significance of research done in each of these countries as well as the typical number of citations for each article. The United States and the United Kingdom have been the leading countries in football training research for players under the age of eighteen. These two countries, with 67 and 60 publications, respectively, have demonstrated a constant commitment to this topic.

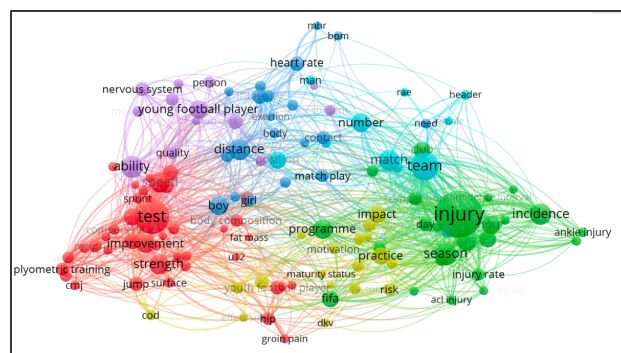
The UK shines out when it comes to both the quantity of articles and the overall number of citations (1596). This suggests that their research has had a significant influence on youth football training. The UK has the highest average citation rate (831.50) among all countries, and their publications have the highest average citation rate as well. This implies that their body of work is not just substantial but also quite important in the academic world.

The global spread of football research is also dominated by several major football countries such as Spain, Australia, Germany, Italy, and Portugal. They made significant contributions, each with a noteworthy average citation rate, indicating the global importance of their research efforts. In addition, Switzerland and Denmark make appearances in the top 10, indicating their dedication to youth football training research. Their average citation rates of 281.00, 285.00, and 318.00, respectively, underscore the quality and influence of their work. Poland, with 18 publications and an average citation rate of 63.00, ranks as the 10th contributor. While it has fewer publications compared to the leading countries, its research has made a significant impact within its niche.

Overall, there are 334 authors and 372 average citation rates for the top 10 countries combined is emphasizing the significance of football training research for young players under 18 on a global scale. The top 10 countries were dominated by European and American continent countries. In Asia and Africa continent, there are China (16 authors) and Tunisia (12 authors) as the top countries with the most authors in football training research publications. The data serves as a valuable resource for understanding the international scope and importance of research in this field, making it an essential reference for academics, policymakers, and sports enthusiasts.

### *Keyword Clusters Pattern in Football Training for Young Players Under 18 Years Old's Research Trend in the Last 15 Years*

Research on football training programs for young players under 18 years of age over the last 15 years has several 6 keyword clusters that reflect various research focuses. The first cluster, involving words such as agility, balance, body composition, and CMJ, indicates that research at that time has mostly discussed the physical and agility aspects of young players. Research with a focus on developing physical abilities and balance is the center of attention for improving the performance of young football players. The second cluster highlights injury issues, especially those related to ACL injuries, knee injuries, ankle injuries, and injury burden. This research explores risk factors and injury rates to improve the safety and health of child football players. In this cluster, research is more focused on injury risk analysis and effective prevention strategies.

**Fig 3.** Keyword Cluster Pattern in Football Training Research for Young players in the last 15 years

The third cluster focuses on football training and its impact on heart rate, training intensity, physical activity, and football training in general. By highlighting the physiological aspects of football training, research in this cluster aims to better understand the extent to which it can influence the health and fitness of young players. The fourth cluster addresses the psychological and social context in the development of child football players. Involving words such as childhood, coaching practice, maturity status, motivation, and risk factor, research in this cluster tends to investigate non-physical factors that influence player development.

The fifth cluster, consisting of words such as ability, effectiveness, experiment, nervous system, and indicator, describes research that focuses more on the evaluation and assessment of training programs. The focus of research in this cluster is more related to how effective certain training programs are in improving abilities and measuring certain performance indicators in young football players. The sixth cluster includes words such as male, female, goalkeeper, position, and team, indicating that research also pays attention to the differences and characteristics between male and female players, the role of goalkeeper, player position, and teamwork in the context of training programs for young players under 18 years old. In all, these five clusters reflect the diversity of research efforts to investigate and improve football training programs for youth players.

**Table 3.** Top 10 Cited Publications in Football Training Research for Young players Under 18 Years Old in the Last 15 Years

| No | Author                           | Total Cited | Research purposes                                                                                                                                                                                                                        | Methods                                                                                                                                                                                                                     | Results                                                                                                                                                                                                                   |
|----|----------------------------------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | (Waldén et al., 2012)            | 292         | To evaluate the effectiveness of neuromuscular training in reducing the level of knee injury in adolescent female football athletes.                                                                                                     | Stratified cluster randomized controlled trial with clubs as the unit of randomization.                                                                                                                                     | Based on Cox Regression analysis, there was a 64% reduction in knee injury rate. There was no significant reduction in secondary outcomes.                                                                                |
| 2  | (Mills et al., 2012)             | 155         | Identify factors that influence the development of football athletes at a young age                                                                                                                                                      | Interviews study with 20 coaches contacted who met the criteria, 10 agreed to participate in the study representing a 25% sample of all academies that currently function in English football.                              | The identification results show that awareness is the basic element for a young athlete to develop to a professional level.                                                                                               |
| 3  | (Folgado et al., 2014)           | 147         | To identify how tactical collective behavior varies with age in different small-sided game formats.                                                                                                                                      | Experimental study with Thirty youth players (mean 9 SD; age 10,539 1.81) participated in this study, divided by age group: 10 players U9 (age 8,590.53); 10 players U11 (age 10,490.52) and 10 players U13 (age 12,790.48) | Length and width ratio and centroid distance are useful measures of tactical performance in small-sided games in youth football.                                                                                          |
| 4  | (Mendez-Villanueva et al., 2013) | 138         | To quantify match play intensity distribution in young football players in relation to age, playing position and physical fitness.                                                                                                       | Correlations study with 103 highly trained young players (Under13 to Under 18) during 42 international club games.                                                                                                          | There was a correlation between max aerobic speed (MAS) and the furthest distance traveled above MAS for all positions except striker. Heart rate (HR) did not differ across positions and age groups.                    |
| 5  | (Randers et al., 2010)           | 128         | Aimed to examine the activity profile, heart rate, and metabolic responses in an untrained male and female small-sided football game. In addition, it also looked at the effect of the number of players in a small-sided football game. | Experimental study with untrained males (UM, n=26) and females (UF, n=21), young players aged 9 and 12 years (C9+C12, n=75), as well as homeless (HM, n=15), middle-aged (MM, n=9) and elderly (EM, n=11) men.              | Small-sided football games have the potential to physiologically adapt and improve performance through regular practice for different types of study groups.                                                              |
| 6  | (Michailidis et al., 2013)       | 122         | This study aimed to determine whether preadolescent boys exhibit plyometric trainability or not.                                                                                                                                         | Experimental Approach to the Problem                                                                                                                                                                                        | These data indicate that (a) prepubertal boys exhibit considerable plyometric trainability, and (b) when football practice is supplemented with a PT protocol, it leads to greater performance gains.                     |
| 7  | (Häggglund et al., 2013)         | 113         | To evaluate team and player compliance with an NMT program in adolescent female football and to study the association between compliance and acute knee injury rates.                                                                    | Prospective cohort study based on a cluster randomized controlled trial on players aged 12–17 years with 184 intervention teams (2471 players) and 157 control teams (2085 players).                                        | Players with high compliance with the NMT program had significantly reduced ACL injury rates compared with players with low compliance. Significant deterioration in team and player compliance occurred over the season. |
| 8  | (Deprez et al., 2015)            | 109         | To determine the influence of anthropometry, physical performance, and motor coordination on dropping out of professional football training programs and future contract status.                                                         | There were 2-study approaches conducted. In both the same methods, we used an experimental approach to the problem.                                                                                                         | Anthropometric characteristics, maturity, fitness and motor coordination were successful in predicting the future careers of youth football players.                                                                      |

**Table 3** (continued)

| No | Author                                   | Total Cited | Research purposes                                                                                                                                                                                                                         | Methods                                                                                                                                    | Results                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----|------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9  | (Ramírez-Campillo, Burgos, et al., 2015) | 109         | The aim of the study was to compare the effects of bilateral, unilateral, or combined bilateral and unilateral plyometric training (PT) on muscle power output, endurance, and balance performance adaptations in young football players. | Experimental Approach to the Problem                                                                                                       | The current study showed that bilateral, unilateral, and combined bilateral and unilateral PT ensured significant improvement in several muscular power and endurance performance measures in young football players. However, the combination of unilateral and bilateral drills seems more advantageous to induce superior performance improvements.                                                                                                              |
| 10 | (Kilding et al., 2008)                   | 92          | The aim of this study was to determine the suitability and effectiveness of “The 11” for younger football players.                                                                                                                        | Experimental study with twenty-four [12 experimental (EXP), 12 control (CON)] young football players (age $10.4 \pm 1.4$ yr) participated. | Given the observed improvements in the physical abilities and the perceived benefits of “The 11”, it would appear that a modified version of the program is appropriate and should be included in the training of young football players, for both physical development and potential injury prevention purposes, as well as to promote fair play. To further engage young football players in such a program, some modifications to “The 11” should be considered. |

#### *Top 10 Cited Publications in Football Training Research for Young players Under 18 Years Old in the Last 15 Years*

Based on the research data that has been presented, we can identify several major themes that cover various aspects of the development and understanding of the world of football, especially for young players. The following are five major themes that can be drawn from the research results.

#### **Factors in the Development of Young Football Players**

The studies by Mills et al. (2012) and Deprez et al. (2015) offer comprehensive understanding of the elements that are crucial to young football players' development. In order to learn more about the elements thought to be important in the player development process, Mills et al. decided to interview coaches. The study's findings support the notion that awareness is a prerequisite for young athletes to succeed at the professional level. Insight into elements like mindset, drive, and commitment that are essential in developing good athletes is given by coaches.

Conversely, studies conducted in 2015 by Deprez et al. broadened this view to incorporate motor coordination, physical performance, and anthropometric measurements as indicators of future success in young athletes. Through the use of experimental techniques, this study demonstrates how young football players' future careers can be predicted by their anthropometric traits, maturity level, degree of fitness, and motor coordination. This research offers a compre-

hensive understanding of the variables that football teams and academies might consider while molding and developing their young potential by integrating these various facets. These results could significantly impact initiatives aimed at enhancing youth football player development programs.

#### **Tactical Analysis and Collective Behavior in Small-Sided Games**

Folgado et al. (2014) research significantly advanced our knowledge of collective behavior and tactical analysis in the setting of small-sided football games for young players. This study investigates differences in collective tactical performance using particular factors by involving three distinct age groups. The findings demonstrated that the centroid distance and pitch length to width ratio emerged as helpful metrics in evaluating and comprehending the dynamics of small-sided play at various age levels. These results shed light on how tactical comprehension changes with age and could serve as a foundation for the creation of training regimens that are more beneficial at particular developmental stages.

Furthermore, this study can offer a more profound understanding of the tactical components that should be prioritized in the instruction and growth of young football players. Coaches are able to create training regimens that are more suited to the individual development stages of their players by seeing how behavior changes collectively as individuals age. A solid foundation for the development

of young players' football potential can be laid by providing an appropriate training environment that enhances their collective decision-making and football skills. This can be achieved through the use of in-depth tactical analysis.

### Game Intensity and Activity Profile in Young Football Players

Mendez-Villanueva et al. (2013) and Randers et al. (2010) conducted studies on game intensity and activity profiles in young football players that offer detailed insights into the way that young players react to different activities during football games. Mendez-Villanueva et al. (2013) found a link between maximal aerobic speed (MAS) and highest distance traveled above MAS for all playing positions, with the exception of striker, using 103 highly trained youth football players. Furthermore, young players, youth, and adult men participated in small-sided football games as part of Randers et al. (2010) research. Randers et al. (2010) found that regular practice of tiny football games can lead to physiological adaptation and improved performance for various study groups.

This study advances our knowledge of how young football players' bodies react to the intensity of a game and adjust accordingly. These two studies provide valuable insights into the intensity distribution and activity profile during play, which may be used to inform more targeted and efficient training plans for young football players. These results may also have a significant impact on how young football players manage their health and exercise regimens, assisting coaches and coaching staff in creating workout plans that take into account the players' unique physiological and physical makeup.

### Plyometric Training and Its Effects on Preadolescent Players

An in-depth understanding of the impact of plyometric training on young football players' performance is provided by studies conducted on preadolescent players by Michailidis et al. (2013) and Ramírez-Campillo, Burgos, et al. (2015). Preadolescent boys demonstrated notable levels of adaptability to plyometric exercise, according to Michailidis et al. (2013), suggesting that this type of training can have a major positive impact on performance. In this regard, Ramírez-Campillo, Burgos, et al. (2015) research further demonstrated that, for young football players, combining bilateral and unilateral plyometric training produced greater increases in a number of muscle performance and endurance indices.

The notion that plyometric training might be an advantageous part of a preadolescent player's training regimen is supported by these results. This study contributes significantly to the understanding of the kinds of training that can have the greatest effects on young football players' physical development and performance by highlighting the advantages of plyometric training and even assessing variations of bilateral and unilateral approaches. For coaches and coaching staff working with preadolescent athletes to enhance their physical capacity and technical skills, this offers a more focused and in-depth perspective.

### Injury Prevention and Neuromuscular Training in Adolescent Football Players

Important information about how certain therapies, like neuromuscular training, might reduce injuries in adolescent

football players is provided by Walden et al. (2012) and Hägglund et al. (2013). A cluster randomized controlled trial design was employed by Walden et al. (2012) to assess the efficacy of neuromuscular training in lowering the incidence of knee injuries among female teenage football players. The findings revealed a noteworthy 64% decline in the incidence of knee injuries. While secondary outcomes did not significantly decrease, this study offers a solid foundation for integrating neuromuscular training into youth football player training regimens.

Hägglund et al. (2013) monitored the use of a neuromuscular program in youth football for females and assessed the degree of program compliance among the team and individual players. According to the findings, players who adhered to the program closely reduced their risk of anterior knee ligament (ACL) injuries in comparison to individuals who did not. The conclusion highlights the vital role that preventative interventions play in improving the health and performance of these young football players by suggesting that knowledge of and adherence to neuromuscular training programs can play in lowering the risk of injury in young football players.

### Discussion

Football has been the subject of extensive research over the past 15 years, and there has been a notable rise in the number of young players under the age of 18 participating in local leagues and tournaments (Badawi & Nasrulloh, 2023). This growing interest is fueled by player development programs organized by local football federations and investment in football infrastructure (Sanmiguel-Rodríguez et al., 2023). While increased participation provides great opportunities, new challenges arise regarding providing adequate facilities and training to support the development of these young players (Ihsan et al., 2022). Therefore, the role of quality facilities and the development of structured training programs is very important to help young players reach their potential (Nuttouch et al., 2023).

Technical skills, including dribbling, ball control, and kicking ability, are identified as key foundations in football development (Giovanni et al., 2020). Understanding and mastery of these skills are taught through structured and repetitive practice (D'Isanto et al., 2022). Additionally, good physical condition, including strength, speed, endurance, flexibility, and coordination, is recognized as key in supporting a player's performance during long, intense matches (Sulistiyono et al., 2021). Tactical understanding, such as team formation, attack, defense, and strategic decision-making, is also an important focus in player development (Kostíukevych et al., 2020). Mental aspects, including emotional control, maintaining focus, increasing self-confidence, and handling pressure, are recognized as an integral part of football coaching (Godfrey & Winter, 2017).

Matches and competitions are an important stage in player development, providing opportunities for them to apply the skills and knowledge they have learned in real situations (Liu et al., 2016). Quality facilities and experienced support are important factors in successful football coaching (Leite et al., 2023). Evaluation and monitoring of player progress is necessary to identify areas of improvement and set goals (González-Víllora et al., 2015). Apart from the physical and technical aspects, ethical education in football, such as

fair play and sportsmanship, is recognized as important in player development (Kriswanto et al., 2022).

Football coaching is not a stopping process but is ongoing and requires commitment from players, coaches, and their families. Through a structured approach, football players can develop their skills and potential, reach higher levels in the sport, and create a strong foundation for the future of football. By examining research patterns in under-18 football training, bibliometric research brings a useful perspective to the field. Research trends, national contributions, keyword patterns, and most cited publications are all included in the analysis, which offers helpful information for future advancements in the field of football instruction.

## Conclusions

Football research for under-18 youngsters has expanded quickly during the past 15 years. This study demonstrates that football demands not just technical and physical ability but also social, cerebral, and tactical abilities. Football coaching entails routine, systematic practice aimed at fostering fundamental technical abilities, physical fitness, tactical awareness, and mental toughness. A player's growth is greatly aided by competitions and matches, which offer chances to put talents to use in practical settings. Integral components of coaching include holistic teaching, football ethics, and player progress evaluation.

The last fifteen years have seen dynamic research trends, according to bibliometric research data. The number of publications increased significantly, reaching a peak in 2020. Analysis of country contributions shows that the UK and the USA have been the main contributors, with their research having a high impact. Keyword groupings reflect the diversity of research focus, including physical aspects, injuries, psychological aspects, exercise program evaluations, and gender differences.

Further research can be directed toward understanding and integrating holistic aspects of football coaching, including the development of non-physical skills such as leadership, teamwork, and conflict resolution. Further investigation into the use of technology in football coaching, such as video analysis, sensor-based performance measurement, and artificial intelligence applications to provide deeper insight into player progress. Lastly, developing a holistic evaluation method to understand player development based on accountable data.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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## ТЕНДЕНЦІЇ ДОСЛІДЖЕНЬ НАВЧАННЯ ГРИ У ФУТБОЛ МОЛОДИХ ГРАВЦІВ ЗА ОСТАННІ 15 РОКІВ: БІБЛІОГРАФІЧНИЙ АНАЛІЗ

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

Реферат. Стаття: 12 с., 3 табл., 3 рис., 51 джерело.

**Метою цієї роботи** є оцінка тенденцій досліджень навчання гри у футбол молодих гравців віком до 18 років за останні 15 років.

**Матеріали та методи.** Це було дослідження, яке складалося з бібліометричного аналізу та систематичного огляду. Пошук статей, опублікованих із 2008 року, здійснювали за ключовими словами «Навчання гри у футбол» та «Футбольні вправи» з використанням комплексної стратегії в базах даних дослідницьких журналів SCOPUS. 17 жовтня 2023 року було зібрано 1053 статті з 4802 цитуваннями. Після цього 217 статей було відібрано для подальшого аналізу за допомогою комп'ютерного програмного забезпечення VOS Viewer.

**Результати.** Великобританія (67), Сполучені Штати (60) та Іспанія (41) були трьома країнами, які мали найбільше публікацій із навчання гри у футбол. Було 6 кластерів ключових слів, які відображали різні центри зосередження уваги досліджень навчання гри у футбол молодих гравців. На основі 10 найбільш цитованих посилань за тематикою навчання гри у футбол молодих гравців було виділено кілька основних тем, які охоплювали різні аспекти тенденцій та розвитку цих досліджень за останні 15 років, тобто (1) Фактори розвитку молодих футболістів, (2) Тактичний аналіз і колективна поведінка в іграх неповними складами, (3) Інтенсивність гри та профіль активності молодих футболістів, (4) Пліометричне тренування та його вплив на гравців передпідліткового віку та (5) Профілактика травм і нервово-м'язове тренування у футболістів підліткового віку.

**Висновки.** Дослідження футболу для гравців віком до 18 років стрімко зростають. Ця тенденція досліджень показує, що футбол вимагає не лише фізичних і технічних навичок, а й соціальних і психічних аспектів. Подальші дослідження можуть бути спрямовані на розуміння та інтеграцію цілісних аспектів тренерства з футболу, включаючи розвиток нефізичних навичок, таких як лідерство, робота в команді та вирішення конфліктів. Для глибшого розуміння прогресу гравців потрібні подальші дослідження використання технологій у тренерстві з футболу, таких як відеоаналіз, сенсорне вимірювання продуктивності та застосунки штучного інтелекту.

**Ключові слова:** навчання гри у футбол, бібліометричний, молодий гравець, спортивна наука.

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## ЕТАПИ РЕДАКЦІЙНОГО ПРОЦЕСУ

### Попередній розгляд подання (до 2 тижнів)

- призначення редактора;
- перевірка рукопису щодо відповідності тематики журналу;
- технічна перевірка (обсяг рукопису, обсяг анотації, оцінка подання щодо стилістичних та бібліографічних вимог, викладених у Керівництві для авторів);
- визначення актуальності, новизни та оригінальності роботи;
- наявність педагогічного експерименту, його відповідність методології дослідження, яку можна повторити (репрезентативність вибірки, однорідність вибірки за віком, руховою підготовленістю, рівнем спортивної підготовленості, стажем занять, тощо);
- якщо рукопис є оглядовим, то перевіряється використання протоколу PRISMA, який охоплює систематичні огляди та мета-аналізи. Авторам рекомендовано заповнити контрольний список і блок-схему та включити їх до подання;
- перевірка на плагіат.

Якщо рукопис отримав позитивну оцінку, то він спрямовується на рецензування, інакше – відхиляється.

### Рецензування

Підбір та запрошення рецензентів, очікування відповіді на запит (до 2 тижнів). Типовий період, необхідний для проведення рецензування складає чотири тижні.

Всі статті, що оприлюднюються в журналі, проходять рецензування.

Головний редактор журналу направляє статтю на рецензування фахівцям, що мають найбільш близьку до теми статті наукову спеціалізацію. Рецензування проходить за подвійною сліпою схемою.

У процесі рецензування завжди розглядаються:

- етичні аспекти;
- оригінальність твору;
- важливість інформації;
- чіткість та зрозумілість тексту;
- доцільність використання методів дослідження;
- інтерпретація результатів;
- обґрунтованість висновків.

### Прийняти рішення щодо публікації (до 2 тижнів)

- обговорення рецензій: запит нової версії, прийняття або відхилення подання;
- якщо приймається рішення про запит виправленої версії рукопису, то автору надається 2 тижні на підготовку рукопису;
- якщо приймається рішення про прийняття рукопису, то він спрямовується на етап підготовки до публікації.
- якщо приймається рішення про прийняття рукопису, то авторам буде необхідно перерахувати журналу Плату за публікацію статті для компенсування витрат на видання.

### Підготовка до публікації (4 тижні)

- літературне редагування;
- комп'ютерна верстка;
- ознайомлення авторів з макетом;
- виправлення помилок друку та форматування;
- підготовка і завантаження електронної версії журналу.

### Публікація (за графіком)

## EDITORIAL PROCESS

### Preliminary consideration of the submission (up to 2 weeks)

- appointment of an editor;
- checking the manuscript for consistency with the thematic scope of the journal;
- technical check (volume of the manuscript, volume of the abstract, assessment of the submission in terms of the stylistic and bibliographic requirements set forth in the Guidelines for authors);
- determining the relevance, novelty and originality of the paper;
- verifying the presence of a pedagogical experiment, its compliance with the research methods which can be repeated (representativeness of the sample, homogeneity of the sample in terms of age, motor fitness, level of sports fitness, training experience, etc.);
- if the manuscript is a review paper, the use of the PRISMA protocol, which covers systematic reviews and meta-analyses, is checked. Authors are recommended to complete the checklist and the flow diagram and include them in the submission.
- plagiarism check;  
If the manuscript received a favorable assessment, it is sent for review, otherwise it is rejected.

### Peer Review

Selection and invitation of reviewers, waiting for a response to the request (up to 2 weeks). The typical period of time allowed for reviews is four weeks.

All articles in this journal undergo peer review. The editor-in-chief of the journal sends the paper for peer review to experts whose scientific speciality is the closest to the topic of the paper. Peer reviewing takes place under a double-blind scheme.

In each paper, the peer review process always considers:

- ethical aspects;
- originality of the paper;
- the importance of information;
- clarity and comprehensibility of the text;
- expediency of using the research methods; interpretation of results;
- validity of conclusions.

### Making a decision on publication (up to 2 weeks)

- discussion of reviews: request for a new version, acceptance or rejection of the submission;
- if a decision is made to request a corrected version of the manuscript, the author is given 2 weeks to prepare the manuscript;
- if a decision is made to accept the manuscript, it is sent to the step of preparation for publication;
- if a decision is made to accept the manuscript, the author will need to pay the journal the Fee for publication of the paper to compensate for the publication costs.

### Preparation for publication (4 weeks)

- literary editing;
- desktop publishing;
- familiarization of the authors with the layout;
- correction of printing and formatting errors;
- preparation and upload of the electronic version of the journal.

### Publication (on schedule)

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