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Original scientific article

The Effect of Physical Exercise on Functional Capacity and Perception of Well-Being in Older Adults

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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

Study purpose. The study aimed to evaluate the effect of strength training exercises on functional capacity, quality of life and perception of well-being in elderly people.

Materials and methods. It was used a mixed study with sequential explanatory design, in which 25 elderly females between 62 and 85 years participated in a physical exercise program for eight weeks, with a frequency of 3 days and sessions of 58 minutes on average. The Senior Fitness Test battery of test item was conducted with a grip strength test, heart rate monitoring in a 6-minute test, SF-36 health questionnaire and post-intervention focus group oriented to well-being analysis.

Results. Cardiorespiratory capacities, strength and flexibility improved significantly ($p < 0.05$), but agility and heart rate did not change ($p > 0.05$). Scores increased in the 8 quality of life dimensions analyzed, and in subjective well-being, health improvement was identified in both the self-perception and autonomy of daily activities related to vitality, motivation, social interaction and adherence to physical activity. The findings indicate that physical exercise based on strength training improves functional capacity, health-related quality of life and the well-being of seniors.

Conclusions. The findings of this study show that eight weeks of physical exercise based on strength training with affordable means (own body weight, elastic bands and dumbbells) with a frequency of 3 days a week, contribute to improving the functional capacity of strength and flexibility in upper and lower limbs, and cardiorespiratory endurance in older females. This intervention was also found to have a positive impact on quality of life, as well as on the perception of well-being.

Keywords: human physical conditioning, sickness impact profile, physical fitness, emotions, ageing.

Introduction

The percentage of seniors in the world has increased considerably in a relatively short period of time and the physiological changes produced by age increase the incidence of chronic diseases and issues surrounding daily tasks and dependence on third parties (World Health Organization & International Telecommunication Union, 2018). The predominant causes of death due to pathologies are cardiovascular diseases and cancer (World Health Organization, 2019). One of the most relevant risk factors is physical inactivity, given that one in four adults does not meet the global recommendations for physical activity (Pan American Health Organization, 2019) and in older adults this compromises health and quality of life (Ahangar et al., 2017). In Latin America and the Caribbean, the first cause of death in older adults is related to cardiovascular diseases that represent about 25% (Aranco et al., 2018). These are associated with physical inactivity and being overweight, a situation that generates alarm since the rates of insufficient physical activity in older people in South America is between 30-56% in men and 36-69% in women (World Health Organization, 2016).

In Colombia, approximately 6.5 million people were over 60 years by 2019, representing about 13.2% of the total population of which 20.6% accessed the health system due

to circulatory system diseases, 11.1% for musculoskeletal diseases and 2.4% for organic disorders and stress related to mental health (Cubillos et al., 2020).

Regular physical activity has been implemented as one of the strategies at the international level and has been shown to help prevent and treat noncommunicable diseases (NCDs), improve mental health, quality of life, well-being, functional capacity and decrease mortality (Font-Jutglà et al., 2020; Gallegos et al., 2019); these strategies and guidelines have been directed from the recreational, leisure and physical exercise spheres (Ramírez-Villada et al., 2015). In Colombia, the policy on human aging and old age, headed by the National Council of Older Persons, has proposed guidelines focused on the promotion of health and quality of life (QOL), as well as disease prevention, wellbeing, healthy lifestyles and protection of this population group (Minsalud, 2021).

Different studies have shown that targeted physical exercise programs for the elderly improve functional fitness (Escalante et al., 2019), gait (Font-Jutglà et al., 2020) and upper and lower extremity muscle strength, especially those that include multicomponent training, evidencing a decrease in body mass index (BMI) (Vargas-Vitoria et al., 2021), mental illnesses such as depression and even dementia, thus contributing to comprehensive well-being (Durán-Agüero et al., 2017). In this sense, such programs stand out in promoting actions that generate an increase in quality of life justified in the perceptions from physical and mental well-being, independence and social integration (Vargas-Vitoria et al., 2021); however, despite the fact that several researches have focused on the link physical activity has with functional condition and health-related quality of life (Castro-Coronado et al., 2021; Poblete et al., 2015), studies focusing on the possible relationship between physical activity and well-being are limited.

However, it is of utmost importance to analyze studies that combine physical exercise, functional capacity, quality of life and well-being in older people from a holistic perspective by integrating quantitative and qualitative approaches for a broader understanding of the phenomenon. The objective of this study was to evaluate the effect of physical exercise based on strength training on functional capacity, quality of life and perception of well-being in older adults in a locality of the city of Bogotá, Colombia.

Materials and Methods

Study Participants

Twenty-five elderly female volunteers between the ages of 62 and 85 years (74.20 ± 6.40 years), residents of the Engativá district of the city of Bogotá participated in the study. Prior to inclusion in the study, it was verified that the candidates did not participate in regular physical exercise programs with a frequency of two or more days per week in the last 6 months and those who presented some type of contraindication for the practice of moderate and vigorous physical activity were excluded; particularly uncontrolled heart failure and arrhythmias, myocardial infarction, stroke, angina pectoris, uncontrolled blood pressure, uncontrolled diabetes or persons physically unable to perform physical exercise. The initial sample consisted of 37 candidates, eight of whom were excluded for not attending 80% of the scheduled sessions, which is equivalent to 19 sessions of the 24 planned in eight weeks; four were also excluded due to health limitations that they presented during the intervention, despite having met all the inclusion criteria. The volunteers were informed of the objective as well as the specific procedures of the study and after understanding their participation, they accepted and signed an informed consent form. They were also informed of the possibility of voluntarily terminating their participation at any time. In addition to this, the participants attached a copy of a medical certificate attesting to their health conditions for the performance of physical activity.

Study Organization

The intervention consisted of an eight-week physical exercise program with a frequency of 3 sessions and an average duration of 58 minutes. These sessions were carried out on the same days of the week with one rest day between sessions and two between the last session of the week and the first of the following week. The exercises applied were based on functional training, using body weight, elastic bands and dumbbells as means, under the supervision of 3 professionals specialized in physical exercise. The planning of the sessions was organized according to the level of physical condition of the participants.

The activities were carried out at the Center for Research and Practices in Physical Activity and Sports (CIPAD) of the Corporación Universitaria Minuto de Dios where the information on the variables and categories that are the object of this study was collected before and after the intervention; the program was conducted at the Quirigua Park, sector C, located in the Engativá district of the city of Bogotá, where the training sessions were held taking into account the residential proximity of the participants, as well as the environmental and logistical conditions for its execution. The Structure of the Physical Exercise Program, Pre: Battery Senior Fitness Test (SFT) and Health-related quality of life (SF36), Intervention: 3 sessions/week – 58 minutes, Heat intake: 15 minutes, Functional exercise: 24-32 minutes Sequence: 3 upper limb exercises and 3 lower limb exercises, Means: Own weight – elastic bands – dumbbells, Load: 3 sets between 6 and 8 repetitions with 50-60 s of recovery. Post: Battery Senior Fitness Test (SFT), Health-related quality of life (SF36) and Focus group perception of well-being and its relationship with physical exercise.

Each session was divided into three moments: 1) warm-up consisting of movements integrating the largest number of muscles followed by dynamic stretching for 15 minutes; 2) functional exercises lasting between 24 and 32 minutes, using own body weight, elastic bands and dumbbells as training means in accordance with the participants' level of progress; the selected exercises emphasized the muscles of the appendicular skeleton, and in the same action, the core muscles as stabilizers of the movements; the progression of the load was based on periodization by stages, adaptation of the exercises, incorporation of external resistances, difficulty in the base of support and the combination of increased function with resistances (Heyward, 2008).

The sessions were organized so that the first three exercises were performed on the lower limbs, followed by

Table 1. Periodization and Organization of the Load during the Intervention

Week	1-2	3-5	6-8
Stadium	**Conditioning**	**Progress 1**	**Progress 2**
Exercises	MMSS: Triceps extension on the wall, Triceps extension with fit-ball, Biceps flexion fixed bar. MMII: Get up from the chair, Free squat, Lunge with chair support	MMSS: Triceps extension, Curl biceps, Lateral shoulder flexion, Lateral shoulder extension. MMII: Free squat, Unsupported Lunge, Side steps.	MMSS: Curl biceps, triceps extension overhead, Knee shoulder press, Shoulder abduction. MMII: Free squat, Unsupported lunge, Dead weight.
Volume	3 series x 6 rep	4 series x 8 rep	5 series x 8 rep
Series duration	20 s	30 s	30 s
Rest	60 s	50 s	50 s
Intensity	OMNI-GSE 5-6	OMNI-GSE 7-8	OMNI-GSE 7-8
Middle	Body weight	Bands	Bands - dumbbells
Total duration	24 min	27 min	32 min

MMSS = Upper Extremity Exercises; MMII = Exercises for lower extremities; repetition = repetitions; s = series duration in seconds; OMNI-GSE = effort perception scale adapted for group classes with older people; min = total duration of the session in minutes.

three exercises on the upper limbs, thus completing a series. In relation to the load, the number of series was initially established at three, the number of repetitions per exercise at six, and the recovery time of one minute during the first two weeks; subsequently, the load was increased every three weeks until reaching four series of eight repetitions with a recovery of 50 seconds in each exercise, aspects that can be observed in more detail in table 1.

As an element of subjective control of intensity, we used the OMNI-GSE effort perception scale, adapted for group classes with elderly people (Da Silva-Grigoletto et al., 2013). 3) once the CORE phase was finished, stretching was performed for 15 minutes allowing a return to calm and relaxation. The intervention was based on the general principles of exercise prescription: frequency, intensity, duration, type, volume and progression of exercise (Heyward, 2008).

Three variables were the object of this study: functional capacity, quality of life and well-being; also, basic anthropometric measurements were taken to characterize the participants.

Anthropometric Parameters: The data collection of basic anthropometric measurements was performed based on the guidelines of the Nutrition Group of the Spanish Society of Geriatrics and Gerontology (Camina- Martín et al., 2016) and those of the Ministry of Health and Social Protection of the Republic of Colombia (2021) related to nutritional assessment in older adults; these measurements were height determined with a portable stadiometer (SECA 213) with an accuracy of 0.1 cm, total body mass with an Omron scale (HBF-514C) with an accuracy of 0.01 kg and body mass index (BMI).

Functional Capacity: For the functional capacity variable, the Senior Fitness Test (SFT) battery was used, consisting of seven tests that allowed the evaluation of muscular strength and endurance (elbow flexion; sitting down and getting up from the chair), cardiorespiratory capacity (stationary walking for two minutes; walking for 6 minutes), flexibility (joining hands behind the back; sitting down and reaching for the foot) and agility (getting up, walking and sitting down again), whose protocol was subject to the provisions of Rikli and Jones (2013). In addition to this battery, the prehensile strength test was applied, carrying out the ACSM protocol (Ligouri, 2021) using a digital prehensile dynamometer (Camry model EH101) with an accuracy of 0.1 kg. As for the 6-minute test, which is part of the SFT battery, heart rate was monitored with Polar® A300 heart rate monitors to establish the maximum average heart rate reached (in beats per minute [bpm]). The tests were performed one week before starting the physical exercise program and one week after its completion at times between 8:00 and 10:00 in the morning.

Health-Related Quality of Life: For the collection of information on this variable, the survey technique was used by means of the SF-36 questionnaire in its standard version developed by Ware et al. (1993), consisted of 36 questions divided into 8 dimensions in which the degree of physical function (10 items), physical role (4), bodily pain (2), general health (5), vitality (4), social function (2), emotional role (3), mental health (5) and health transition (one item) were measured. They were completed by means of a personal interview guided by the professionals responsible for the study, prior to the anthropometric and functional tests programmed before and after the intervention. To estimate the degree of health status in each dimension, the score was standardized from 0 to 100 so that the higher the score, the better the health status.

Perception of well-being: As a qualitative category of this study, the perception of well-being was developed under a phenomenological design using the post-intervention focus group as a data collection technique, to interpret the experiences lived by the participants of the physical exercise program. The focus group was organized based on the construction of a semi-structured guide composed of nine questions distributed in two categories: functional status (four questions) and emotional well-being (five questions), so that they were representative for the study in relation to the objective (Ñuapas et al., 2018); these were validated by three experts in the areas of sociology, human development and physical education, by means of the indicators of sufficiency, clarity, coherence and relevance (Hernández-Nieto, 2011); the result of the total content validity coefficient was good (CVC 0.89) understanding that to a high degree, the questions were accepted by the three experts.

The sample was divided into two groups, one of 13 and the other of 12 participants, to include enough elderly people so that the information collected would be diverse, but taking care that there would be no discomfort in sharing opinions and experiences (Onwuegbuzie et al., 2009); each older person authorized their participation and the recording of the session through informed consent; the session lasted approximately two hours, moderated by an expert in qualitative research; a mobile device with a sound recorder application was used to record the sessions; for the transcription of the data, the "Word" application of the Microsoft Office 365 package was used, in which a file was created for each session to later load them and conduct a thematic analysis of the data collected in this study.

This study was conducted in accordance with the parameters for research on human subjects defined by the Helsinki Declaration of the World Medical Association (WMA, 2013) as well as the considerations outlined in the scientific, technical and administrative standards for health research (Ministry of Health and Social Protection Republic of Colombia, 1993). All procedures applied were approved by the Research Ethics Committee of the Corporación Universitaria Minuto de Dios (code: 24_06_20).

Statistical Analysis

The G*power software version 3.1.9.7 was used to calculate of the estimate of statistical power and sample size, in which a large effect size (0.8) determined from the review of similar studies, an expected power (β) of 0.95 and a probability of error (α) of 0.05 were indicated. As a result, the minimum estimated sample was 23 participants, which corresponds to the sample size of this study of 25 participants. For the statistical analysis of functional capacity and health-related quality of life (HRQL), the IBM SPSS Statistics software version 23.0 was used, and additionally, the G Power program version 3.1.9.7 was used to determine the effect size of the differences in the inferential tests. For all quantitative variables under study, the mean (M) and standard deviation (SD) were calculated; for the comparison of M before and after the intervention, the t Student test for related samples was used after checking the assumption of normality using the Shapiro-Wilk test; in relation to the effect size derived from the intervention, the Cohen's d test was used. The significance level (α) established in the analysis was .05. Regarding the qualitative analysis of the category of well-being, a hermeneutic structure was developed based on the proposal of Hernández and Mendoza (2018), which consisted of the transcription of recordings of the interviews in the focus groups by means of a double-entry matrix (group-responses). Subsequently, open coding was carried out, which consisted of the organization and selection of key quotes articulated in the theoretical categories; then the axial coding technique was applied, determined by the resulting hierarchical relationships between the semantic families (social, physical and psychological spheres) and the emerging categories (companionship, family, inclusion, health, exercise, physical condition, self-perception, motivation, spirituality, vitality, emotionality, and learning). Finally, relational networks were structured between each category for the holistic understanding of the appraisals and social experience in the participation of the physical exercise program (Rivera et al., 2014).

Results

The results are presented in two sections: the first is focused on report the basic characteristics, functional capacity and perception of quality of life of the participants through the analysis of quantitative data before and after the intervention; the second section examines the perception of well-being through the interpretation of the narrative of the participants from the experience after participation in the physical exercise program. Table 2 presents the initial anthropometric characteristics of the 25 participants who completed all phases of the study.

Functional Capacity

Table 3 presents the results of the functional capacity variables strength and flexibility in lower and upper limbs, agility and cardiorespiratory endurance with their respective descriptive statistics based on means, pre- and post-intervention standard deviation and mean differences (Dif-M), as well as the comparative inferential statistic (t), p-value and effect size (d). After eight weeks of intervention, we found an increase in right upper extremity muscle strength (ESD) in the dynamic elbow flexion test, with a large effect size (95% CI [1.53-3.03]); similar results were found in the left upper extremity (ESI) with a medium effect size (95% CI [0.32-1.21]). Regarding prehensile strength, the tension exerted (kg) in both limbs increased after the intervention with statistical significance, ESD 95% CI [0.33-1.23] and ESI considering a large effect size, 95% CI [0.430-1.36]). Regarding the sit-to-stand test which assessed lower limb strength, the results show that the number of repetitions increased with statistically significant difference and a large effect size, 95% CI [0.69-1.72].

Table 2. Anthropometric characteristics of the participants (n=25)

	M	Me	SD	Rank	EE	CI 95%	
						Li	Ls
Age, years	74.20	74.12	6.40	22.65	1.28	71.56	76.84
Stature, cm	150.31	150.00	7.07	28.00	1.41	147.39	153.23
Body mass, kg	63.64	64.80	11.96	42.80	2.39	58.71	68.58
BMI, kg/m^2	28.14	27.54	4.81	16.06	0.96	26.15	30.12

cm = centimeters; kg = kilograms; BMI = body mass index; M = Mean; Me = Medium; SD = Standard deviation of the mean; EE = Standard error of the mean; CI 95% = effect size confidence interval from the lower (Li) and upper (Ls) limits.

Table 3. Variables of functional capacity and behavior after eight weeks of intervention (n=25)

Capacity	Test	Extremity	Pre-intervention	Post-intervention	Dif-M	East	d
			M ± SD	M ± SD			
Strength	PRF [kg]	Right hand	14.87 ± 2.81	15.71 ± 2.81**	0.84	3.92	0.78
		Left hand	15.23 ± 3.56	16.38 ± 3.51**	1.15	4.52	0.90
	ElF [rep-30s]	Right arm	14.32 ± 3.44	17.88 ± 3.46**	3.56	11.43	2.29
		Left arm	14.32 ± 3.38	16.72 ± 3.26**	2.40	3.86	0.77
	SL [s]	bilateral	14.68 ± 3.60	17.40 ± 3.32**	2.72	6.06	1.21
Flexibility	CHB [cm]	Right arm	-13.52 ± 6.57	-11.28 ± 6.67**	2.24	6.44	1.29
		Left arm	-20.06 ± 8.13	-17.40 ± 6.93**	2.66	4.05	0.81
	SRF [cm]	Right foot	-10.40 ± 10.13	-7.84 ± 8.63*	2.56	3.47	0.69
		Left foot	-9.11 ± 8.25	-5.92 ± 7.75**	3.19	6.24	1.25
Agility	GWS [s]	bilateral	5.53 ± 0.68	5.41 ± 0.70	-0.12	685.00	-0.28
C. capacity	M2M [Rep.]	Bilateral	68.08 ± 16.71	76.20 ± 17.27**	8.12	4.86	0.97
	W6M [m]	Bilateral	455.37 ± 89.01	570.59 ± 120.33**	115.22	6.81	1.36
	HR6M [ppm]	Not applicable	117.44 ± 10.76	115.80 ± 11.40	-1.64	-1.65	-0.33
	%HR6M	Not applicable	75.12 ± 7.33	74.08 ± 7.79	-1.04	-1.62	-0.32

C. capacity: Cardiorespiratory capacity; M: Medium; DS: Standard deviation; Dif-M = difference between the means of the dimension; Est = Test statistic; **: significant values, $p < 0.001$; *: significant values, $p < 0.05$; d = Cohen's d effect size; PRF: Prehensile Force; ElF: Elbow flexion; SL: Sit back and get up from the chair; CHB: Clasp your hands behind your back; SRF: Sit and reach the foot in sedation; LCS: Getting up, walking, and sitting again; M2M: Stationary march in 2 minutes; W6M: Walk 6 minutes; HR6M: Maximum heart rate at the end of the Test walk 6 minutes; %HR6M: % HRmax at the end of Test walk 6 minutes.

In the flexibility capacity of the upper extremities (shoulder joint), a decrease in the distance between the fingers was identified in the test of joining the hands behind the back, which assumes an improvement in the two extremities with a large effect size (ESD: 95% CI [0.75-1.81]; ESI: 95% CI [0.35-1.26]). In relation to lower limb flexibility (hip joint) from the sit and reach test, it is evident that the distance between the distal phalanx of the toes and the tip of the foot decreased, considered statistically significant with moderate (EID: 95% CI [0.25-1.13]) and high (EII 95% CI [0.71-1.77]) effect sizes.

For agility, it was observed that, when comparing the means of the time used in the test of standing up, moving and sitting down again, there were no significant changes between the initial test and the post-intervention. When observing the effects of physical exercise on this capacity, the results showed that, in the 2-minute stationary walking test, the number of repetitions performed increased significantly with a large effect size (95% CI [0.49-1.44]). Along the same lines, in the 6-minute walk test, a statistically significant increase in the distance covered by the participants was observed with a large effect size (95% CI [-0.81-0.12]). Additionally, during the 6-minute test, the heart rate was recorded at the end of the test, the results of which show that when comparing the initial test of maximum heart rate with the recording at the end of the intervention, no significant changes were found ($p > 0.05$).

Health-related Quality of Life (HRQOL)

Table 4 presents the effects of physical exercise on the dimensions of health-related quality of life (HRQOL) of the 25 participants from the descriptive statistics of the standardized scores of the SF-36 questionnaire mean (M), standard deviation (SD) pre- and post-intervention, and the differences of these (Dif-M), as well as the comparative inferential statistic (t), the p-value, the effect size (d) and the confidence interval of the effect size (CI95%).

The results of the perception of HRQOL indicate that the scores in the eight dimensions increased significantly ($p < 0.05$), highlighting that general health, physical role, physical function, emotional role and social function were those with the highest scores, with large effect sizes ($d > 0.80$), while the dimensions bodily pain, mental health and vitality, although they improved, obtained medium effect sizes ($d => 0.5$). Regarding the overall quality of life score, it was observed that it increased significantly with large effect sizes.

Perception of Well-being

The qualitative results of this study based on the perception of well-being are presented in Figure 1, which exposes the theoretical categories (TC) functional status for quality of life and emotional well-being, which were the starting point for the interpretation of the narrative resulting from the focus groups; consequently, 3 semantic families (SF) and 12 emergent categories (EC) were identified.

Functional Status for Quality of Life

In this TC, the participants perceived the degree of performance when carrying out activities of daily life, this is interpreted as the levels of performance capacity and its relationship with being healthy. Two SF were identified

Table 4. Health-related quality of life dimensions before and after the intervention

Dimension	Pre Score	Post Score	Dif-M	t	gl	d	CI 95%	
	M±SD	M±SD					Li	Ls
Physical Function	42.00±14.22	58.00±11.27**	16.00	9.65	24	1.93	1.25	2.59
Physical Role	39.00±14.58	59.00±17.50**	20.00	4.90	24	0.98	0.49	1.45
Body Pain	64.08±20.34	71.88±16.47**	7.80	3.97	24	0.79	0.34	1.24
General Health	29.60±6.67	57.28±11.25**	27.68	11.94	24	2.39	1.60	3.16
Vitality	76.40±11.50	80.80±11.43*	4.40	2.53	24	0.51	0.08	0.92
Social Function	71.50±12.25	83.50±8.63**	12.00	4.10	24	0.82	0.36	1.27
Emotional Role	23.99±24.58	38.65±15.77**	14.66	4.34	24	0.87	0.40	1.32
Mental health	81.44±9.58	87.36±7.89**	5.92	3.82	24	0.76	0.31	1.20
Global Score	58.53±5.53	71.32±5.39**	12.79	16.99	24	3.40	2.36	4.43

Dif-M = difference between the means of the dimension; t = Statistic of the student's parametric test t for related samples selected according to the result of the Shapiro Wilk normality test; gl = degrees of freedom; p = value that is contrasted with the proposed significance level of 0.05; **: significant values, p< 0.001; *: significant values, p< 0.05; d = Size of the effect obtained from Cohen's d test; CI 95% = effect size confidence interval from the lower (Li) and upper (Ls) limits.

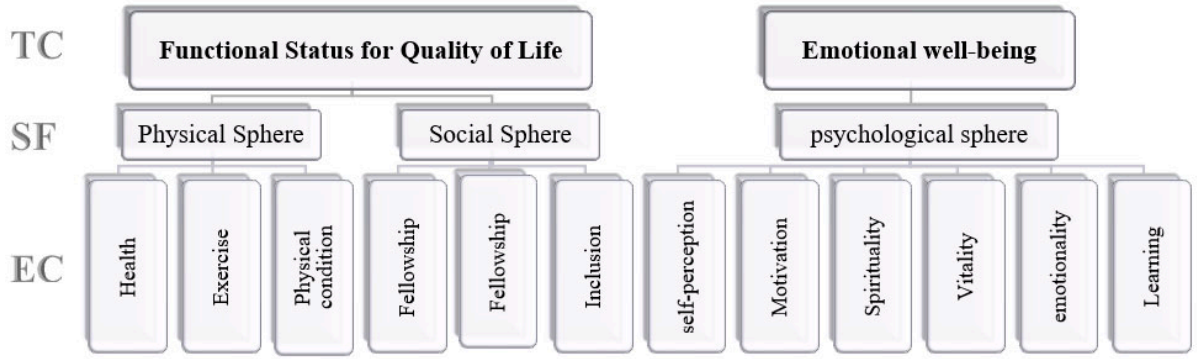

Fig. 1. Categories resulting from the focus group.
Note: TC = theoretical category; SF = semantic family; EC = emergent category

based on recurrence: Social sphere (14.3%) and physical sphere (24.8%). The former contains the SGs companionship (5.5%), inclusion (4.4%) and family (4.4%). Companionship arises from the interaction and harmony of relationships among the participants: "it is very beneficial and satisfying to spend time with classmates and all of you teachers"; as for the EC inclusion, the elderly participants indicated that they are a fundamental part of the group due to the recognition of individual capacities: "we have noticed that there is no discrimination because if one person can do the exercises well, and the other can't, they take us all into account, they are very patient with us and help us to improve"; finally, the participants associate the interaction as a manifestation of the EC family since they state: "we are not really a group but like a family and I feel very happy to be spending time with you".

Regarding the SF physical sphere (frequency 24.8%), it groups the SGs health (17.1%) exercise (4.4%) and physical condition (3.3%), and it is observed that they have an influence on the perception of autonomy. This is interpreted considering that the appreciation of QoL in older adults is directly related to personal satisfaction, and the optimal state of physical health (Ferradas & Freire, 2016). From this SF, it is highlighted that in the EC of Health there is an outstanding recurrence with respect to the other EC, in which it is interpreted that the elderly manifest an estimation of health improvement after the participation in the program: "now I feel that my health has improved a lot" which is articulated with the EC exercise that denotes the improvement of functional autonomy from the changes perceived during and after the intervention: "the exercises have helped me a lot because my bones were very stiff and in the short time I have been doing them I have felt much better". The physical condition EC aspects associated with the perception of weight reduction are highlighted: "I started losing weight little by little and with you I have lost 3 kilos"; and participants say they are feeling healthy thanks to the practice "stretching has strengthened me a lot it has helped me a lot for my health I do not feel sick". These appreciations become a decisive element for the participants to adhere to the program, since a good physical condition favors independence, obtaining better results in the quality of life, through various collective activities that include physical exercise (Villarreal-Angeles et al., 2021).

Emotional Well-being

The TC Emotional well-being (frequency 60.9%) in the SF of the psychology sphere is directly related to mental

health and the perception that the older person has of his/her current situation, i.e. psychological well-being; this SF groups together the SGs of self-perception (15.5%), spirituality (12.2%) motivation (12.2%) motivation (12.2%) vitality (10%), emotionality (6.6%) and learning (4.4%). In terms of frequency in this SF, the EC of Self-perception is evidenced as relevant in which the discursive recurrence in specific states is highlighted and is articulated with the multidimensional model of psychological well-being from the dimensions of acceptance with oneself, psychosocial links, autonomy and control of situations, expressing "feeling alive, feeling that despite my years I feel very well and I feel fulfilled". Particularly present are the emergent relational networks which denote the appreciation of older adults in aspects such as feeling ready for action from the EC motivation: "wanting to do things, feeling good, feeling active, feeling alive"; the EC of vitality from the openness to practice: "I am an active person, my physique allows me to do many more sports activities"; physical factors associated with the EC emotionality: "feeling better because I have gained a lot of flexibility, balance and mentality". These three emerging categories are articulated indicating that people feel more satisfied with their lives and willing to do physical exercise, likewise, participating in the program on a continuous basis tends to the understanding of the routines and the EC learning: "well after the exercises we learn, I feel that I can repeat them and now I practice them at home".

On the other hand, it is evident that for the participants the Spirituality EC is fundamental: from this, guidelines regarding gratitude and possibility stand out: "I thank God because first he has given me life, second he has given me strength to do my exercises" and it is related to the motivation EC for participation: "thanks to God for giving me the joy to get up and have that incentive to get ready to go out and exercise". The above is essential for the practice of physical-recreational activities by older adults who, from their self-perception and beliefs, recognize themselves as more vital and emotionally.

Discussion

The aim of this study was to evaluate the effect of physical exercise on functional capacity, HRQOL and PB in apparently healthy elderly females. The proposed training consisted of functional strength exercises using training aids easily acquired by the participants, the exercise progression was differentiated by the number of repetitions and sets, materials used, total time of the sessions and the subjective perception of effort by means of the OMNI-GSE scale.The main findings indicate that eight weeks of physical exercise based on functional training triggers improvements in cardiorespiratory capacity, improving the independence of elderly women, which has an impact on the quality of life (Da Silva et al., 2020). Therefore, it is deduced that, from the proposed intervention, not only is cardiorespiratory endurance related to static walking and 6-minute walk is improved, but also a greater life expectancy can be achieved an important aspect for the participants of this type of program and their close relatives or caregivers by contributing to their health (Yin et al., 2020).

In muscular endurance in upper limbs, a significant improvement is denoted, which is inversely related to cardiovascular risks and mortality (Figueroa et al., 2019). A significant increase in prehensile strength was also evidenced, which, accompanied with lower limb assessment, is considered a practical and relevant biomarker in concurrent general strength for the elderly (Bohannon, 2019).

Regarding strength in lower limbs, the findings indicate that functional muscular resistance training significantly improved this capacity, which coincides with other studies related to the increase of muscular strength, by means of resistance training on unstable bases for 10 weeks and combined exercise of traditional balance and virtual reality for 8 weeks in which in addition to improving strength, so did balance and functional mobility (Eckardt, 2016; Sadeghi et al., 2021); this has a close correspondence with emotional states by counteracting the degree of depression when strength training is combined with aerobic training and a positive influence on levels of health perception (Solà et al., 2019).

In upper and lower limb flexibility, significant changes are observed after participation in the program; data similar to those found in other studies, are associated with the improvements observed in strength training and with studies that demonstrate high performances in joint amplitude ranges in active older adults (Concha et al., 2017; Escalante et al., 2019); likewise, differences between limbs were evidenced, reflecting improvements in the lower limbs (Vaca et al., 2017), which allows the effectiveness of the implemented program to be verified. When referring to HRQOL, older persons directly relate their social role to participation in community activities, which indirectly contributes to physical and emotional stability. Likewise, these programs for the community are oriented to the practice of physical exercise from institutionalized or integrated service projects (Gallegos et al., 2019), as well as in the subjective perception through the pre and post application of the SF-36 questionnaire. At the conclusion of the intervention of the physical exercise program, scores in the dimensions of health perception in general stand out with a significant improvement in the dimensions of role and physical function, results similar to other studies (Gallegos et al., 2019; Ramírez & Triana, 2007).

The effect of functional training programs originates a significant improvement in physical fitness and in the dimensions of quality of life related to health and well-being associated with happiness (Solà et al., 2019; Vargas-Vitoria et al., 2021). With respect to well-being, the resulting discursive interpretation is aligned with other studies that denote the increase of parameters regarding the perception of general health, vitality and social function in participants of programs associated with exercise, and others performed as activities in leisure time and that contribute to the establishment of social relationships or friendships, benefiting the physical and mental health of older adults and in turn, well-being (Paggi et al., 2016). On the other hand, physical activity levels can increase when older adults are allowed activities that contribute to social relationships, i.e., conservation or establishment of friendships, generating improvements not only in physical activity but also in life satisfaction, an aspect observed in another research (Huxhold et al., 2013).

Likewise, this type of physical training has a positive impact on older adults reflected in functional independence (Mora-Vicente et al., 2007), a situation that is related

to subjective well-being and activities of daily living (Almonacid et al., 2021). This aspect was observed by Sotelo et al. (2014) in a group of 150 older adults who participated in a physical activity program, finding an inverse association between muscle mass and frailty criteria, those with less muscle mass in the lower limbs presented lower levels of functional independence.

Another aspect to take into account is that the normal biological process of the older adult conditions to the involution of physical skills, however, physical exercise is devised as a relevant factor in the decrease of such condition (Figueroa et al., 2019); similarly, the process of programs for the promotion health from physical activity, strengthen functional capacity, as well as contribute to positive conditions of subjective well- being and quality of life in the older adults (Honório et al., 2021; Poblete-Valderrama et al., 2015). In this framework, physical exercise programs are oriented by age and gender, taking as a reference the cardiovascular vascular risk factors in participants (Ramírez-Villada et al., 2015), projecting the benefits it brings in functional independence (Alvarez & Alud-Sorao, 2017). Likewise, programs that combine multicomponent physical activity, including aerobic strength, stretching and balance exercises, reduce the level of depression, strengthen cognitive processes (Da Silva et al., 2020). Their systematic application and practice enable the improvement of various physical abilities (Font-Jutglà et al., 2020; Vaca et al., 2017).

Regarding the qualitative analyses performed in the category of functional status for quality of life and the semantic family of physical sphere, it can be understood that QOL in older person is directly related to personal satisfaction, and the optimal state of physical health (Ferradas & Freire, 2016). In addition, to contribute to the adherence to physical activity programs in this population, considering physical, social, economic and psychological particularities of this population (Assumpção et al., 2014). In addition, it highlights the importance of targeted and systematic physical activity programs, proposed by professionals who consider the various factors that may be limiting or facilitating the practice, permanence and adherence to this type of program (Jefferis et al., 2014).

Limitations of the study

This study had limitations in the research design, the monitoring of heart rate and the multicomponent aspect in the training sessions, this factor sometimes means that physiological intensity the subjects are being exposed to is not known. Using subjective methods to solve this difficulty it is suggested that for future research, controlled clinical trials be developed to increase the internal methodological validity, propose multicomponent physical exercise interventions and monitor heart rate as an indicator of internal load control during the sessions. Likewise, it is recommended that male participants be included since this study did not have the minimum required according to the estimation of the statistical power of the sample (n=23).

Interpretation and Generalizability

This study can be a reference to contribute to local and regional programs of physical activity in the elderly using strength training, and to incorporate the methodology applied to multicomponent physical exercise plans. Likewise, and simultaneously, to follow-up on the perception of quality of life and well-being as fundamental axes of active aging by means of the techniques and instruments referenced in this study.

Conclusions

The findings of this study indicate that eight weeks of physical exercise based on strength training with affordable means (own body weight, elastic bands and dumbbells) with a frequency of 3 days a week between 54 and 62 minutes of duration, improve the functional capacity of strength and flexibility in upper and lower limbs, and cardiorespiratory endurance in older women; however, no significant changes were observed in agility and maximum heart rate during the 6-minute test of the SFT battery. It was also found that this intervention had a positive impact on HRQOL as well as on the perception of well-being, which confirms that the systematic practice of physical exercise contributes to maintaining a healthy physical and mental life during aging.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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Вплив фізичних вправ на функціональну спроможність та сприйняття стану здоров'я у осіб похилого віку

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 11 с., 4 табл., 1 рис., 51 джерело.

Мета дослідження. Метою дослідження було оцінити вплив силових тренувальних вправ на показники функціональних можливостей, якість життя та сприйняття стану здоров'я у осіб похилого віку.

Матеріали та методи. Було застосовано змішаний метод дослідження з секвенційним пояснювальним плануванням, в якому взяли участь 25 жінок похилого віку від 62 до 85 років, які протягом восьми тижнів займалися фізичними вправами з частотою 3 рази на день і тривалістю занять в середньому 58 хвилин. Батарея тестів для визначення рівня фізичної підготовленості осіб похилого віку (Senior Fitness Test) включала тест на силу хвата, моніторинг серцевого ритму протягом 6-хвилинного тесту, опитувальник SF-36 з метою оцінки стану здоров'я та фокус-групу після інтервенції, орієнтовану на аналіз самопочуття.

Результати. Показники кардіореспіраторних можливостей, сили та гнучкості значно покращилися ($p<0,05$), проте рівень спритності та частоти серцевих скорочень залишився незмінним ($p>0,05$). Також спостерігалося підвищення результатів у 8 проаналізованих вимірах якості життя, а в суб'єктивній оцінці самопочуття покращення стану здоров'я було виявлено як у самосприйнятті, так і в забезпеченні автономії повсякденної діяльності, пов'язаної з життєздатністю, мотивацією, соціальною взаємодією та дотримуванням режиму фізичної активності. Отримані дані свідчать про те, що фізичні вправи на основі силових тренувань покращують функціональну спроможність, якість життя, пов'язану зі здоров'ям, і стан загального самопочуття осіб похилого віку.

Висновки. Результати цього дослідження показують, що фізичні вправи протягом восьми тижнів, засновані на силовому тренуванні з використанням доступних засобів (власної ваги, еластичних стрічок і гантелей) з частотою 3 дні на тиждень, сприяють поліпшенню показників функціональних можливостей сили та гнучкості верхніх і нижніх кінцівок, а також кардіореспіраторної витривалості у жінок старшого віку. Також було встановлено, що дана інтервенція має позитивний вплив на якість життя, а також на сприйняття стану здоров'я.

Ключові слова: фізичний стан людини, профіль впливу захворювання, фізична підготовленість, емоції, старіння.

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Original scientific article

The Effect of 16-Week Progressive Circuit Training Program on the Health and Skill-Related Fitness Parameters of Overweight University Students

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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

Study purpose. This study examines the effect of a 16-week interval progressive circuit training program on the skill and health-related fitness of overweight university students.

Materials and methods. A total of 72 university students underwent health and skill-related fitness tests before and after a 16-week progressive circuit training program. Paired sample t-tests and Wilcoxon signed-rank tests were used to determine differences between pre- and post-tests.

Results. Significant decrease in BMI, cardiovascular endurance, agility, speed and reaction time was observed after a 16 week progressive circuit training program ($p \leq 0.05$). In contrast, strength, flexibility, coordination and power increased significantly ($p \leq 0.05$). The 16-week interval progressive circuit training programme has a positive effect on the physical fitness among the study participants.

Conclusions. The findings encourage further research into optimized training protocols, long-term sustainability of improvements, and tailored applications for specific population groups, ultimately advancing our understanding of the multifaceted benefits of interval progressive circuit training.

Keywords: circuit training, physical fitness, training progression, overweight, university students, well-being.

Introduction

Physical fitness is a cornerstone of overall well-being (Greenlee et al., 2017), and its importance becomes obvious for university students. A growing concern for students' sedentariness is linked to the advancement of education and technology. The demands of academic life often tether students to desks and screens for extended periods, leaving little room for physical activity. The lack of movement, unhealthy eating habits and stress made the rising epidemic of overweight and obesity among university students. A worldwide trend study published in Lancet Global Health found an insufficient physical activity from 2001 to 2016 reveals that more than one in four adults worldwide fails to get the recommended levels of physical exercise (Guthold et al., 2018). Similarly, a recent study found a significant decrease in doing regular exercise during one's college years compared to the school years before (Alkhateeb et al., 2019).

The sedentary nature of modern university life is related to the surge of overweight rates among university students mirroring global trends (Hojjat, 2021). The accessibility of fast food on campuses, irregular eating patterns, and the allure of convenience contribute to unhealthy weight gain (Maillet & Grouzet, 2023). Beyond the immediate health concerns, carrying excess weight in young adulthood can lead to a cascade of long-term health issues, including diabetes, cardiovascular diseases, and a diminished quality of life (Koliaki et al., 2019). These health issues affect the present well-being of students and their future, which can negatively influence their quality of life and life expectancy.

Aside from the physical implications, excess weight has significant consequences for academic performance (Greeff et al., 2018). It was proven by Poh et al. (2019) which found a strong relationship between overweight and cognitive function, where excessive weight is associated with low academic performance. Decreased attention span and memory impairment are among the cognitive effects on students with excessive weight that hinder their ability

to absorb and retain information (Jirout et al., 2019). Furthermore, lower self-esteem and increased stress are among the major psychosocial consequences of being overweight that can further worsen academic challenges (Robinson et al., 2020). The connection between physical health and academic performance is complex. Students who prioritize their well-being are expected to experience better concentration, problem-solving skills, and overall cognitive function (Borgonovi & Pal, 2016; Barry et al., 2017). In contrast, excess weight may impede these cognitive functions and create a challenging cycle to break.

In the Philippines, the curriculum in tertiary education is considered overloaded (Ortiga, 2014; Durban & Catalan, 2012), especially for teacher education programs. This means that pre-service teachers in the country have a high chance of becoming overweight or obese. Meanwhile, the Commission on Higher Education (CHED) revised the physical education courses for tertiary education as one of their realizations during the mid-COVID-19 pandemic (Order No. 39, 2021). Among the new courses is Physical Activity Towards Health and Fitness (PATHFit) 2 which aims to provide experiences for the students to engage in a variety of exercise programs to maintain and enhance cardiorespiratory and musculoskeletal fitness. Currently, based on my knowledge, there is no study conducted about the effect of the course on the physical fitness of overweight university students, specifically the use of a progressive circuit training program. Relevant fitness programs like circuit training can provide appropriate support, promoting sustainable habits that extend beyond their university years (Seo et al., 2019).

Circuit training is a dynamic and efficient form of exercise that involves a series of structured, timed activities performed consecutively with minimal rest between exercises (Getty et al., 2018; Micielska, 2021). The principles of circuit training revolve around high-intensity intervals and a progressive structure. For the purpose of this study, a 16-week training program was conducted and participated by overweight university students during their PATHFit 2-course schedule for one whole semester. Specifically, this study examines the effect of the implemented program on health-related (body composition, cardiovascular endurance, strength and flexibility) and skill-related fitness (coordination, agility, speed, power, balance and reaction time).

Materials and Methods

Participants

Seventy-two first-year pre-service university students (male 33, female 39; age 18 (36), 19 (25), 20 (11) years old; BMI 27.7 ± 1.4; cardiovascular endurance 108.4 ± 12.2 HR; strength 26.9 ± 4.5 push-ups; flexibility 48.0 ± 9.9 cm; coordination 30.7 ± 6.8 hints; agility 15.8 ± 1.7 secs.; speed 22.3 ± 5.0 secs.; balance 30.9 ± 7.5 secs.; reaction time 15.7 ± 4.4 cm) volunteered to participate in the study (Table 1). The participants were from the same university in the Philippines where their physical fitness was monitored under the Physical Activity Towards Fitness and Health (PATHFit) 2 course. All the participants were handled by the researcher of this study. The present study obtained permission from the participants in the form of written consent. Approval for conducting the study was secured from the recommending and ethics committee of the Sorsogon State University.

Table 1. Participants characteristics

			N = 72
Sex			
Male			33 (45.8%)
Female			39 (54.2%)
Age			
18		yrs.	36 (50%)
19		yrs.	25 (34.7%)
20		yrs.	11 (15.3%)
Health-related fitness			
Body composition	Body Mass Index	BMI	27.7 ± 1.4
Cardiovascular endurance	3-minute step	bpm	108.4 ± 12.2
Strength	90° Push-up	reps.	26.9 ± 4.5
Flexibility	Sit and reach	cm	48.0 ± 9.9
Skill-related fitness			
Coordination	Juggling test	hints	30.7 ± 6.8
Agility	Hexagon agility test	secs.	15.8 ± 1.7
Speed	50m sprint test	secs.	22.3 ± 5.0
Power	Standing long jump	cm	164.4 ± 12.2
Balance	Stork balance stand test	secs.	30.9 ± 7.5
Reaction time	Stick drop test	cm.	15.7 ± 4.4

Abbreviation: yrs., years; BMI, body mass index; bpm, beats per minute; reps., repetitions; cm., centimeter; secs., seconds.

Study Design

The participant's physical fitness (health and skills-related fitness) was tested before and after the 16-week interval progressive circuit training program (Table 2). The tests and program were conducted at Sorsogon State University-Main Campus once a week during the scheduled PATHFIT 2 course of the participants. The course is equivalent to 2 units or 2 hours per week. The participants came from 5 sections that were scheduled every 7:30 to 9:30 from Monday to Friday. The pre-test was a regular physical fitness test conducted before the start of the course. All the participants were instructed to reduce caffeine and high-caloric foods during the semester.

For the purpose of the study, qualified participants were determined by the initial BMI result as overweight (BMI 25-29.9) based on the WHO BMI cut-off (Lim et al., 2017; Muc Da Encarnacao, & NCD Risk Factor Collaboration, 2017) and have no exposure to fitness training in the last 6 months. During the second week of the first semester of 2022-2023 (August 15 to 19, 2022) the pre-test was conducted guided by the researcher-made Physical Fitness Test (PFT) form (body mass index, 3-minute step test, 90° push-up, sit and reach, juggling, hexagon agility test, 50 m sprint, standing long jump, stork balance stand test, and stick drop test). Three trials were conducted to select the best performance of the participants for each test.

The circuit training started after the pre-test (August 22 to December 9, 2022); the participants were given 15 mins. warm-up and 15 mins. cooldown stretching exercises and

were hydrated before, during and after the conduct of the experiment for safety. Moreover, the participants were instructed to jog in place during rests. The post-test was conducted after 16 weeks, which was the final week of the first semester (December 12 to 16, 2022). The results of the tests were also made transparent to the participants for their awareness and confirmation.

Materials and Test Procedure

To record the body composition, the BMI was assessed using a weight machine and tape measure and used the formula for accuracy. To test the cardiovascular endurance, the 3-min. step test was conducted on a sturdy step approximately 12 inches (30 cm) high. Moreover, the agility test was conducted on a flat surface with a hexagonal tape pattern while the 50m sprint was conducted on a straight track and the stork balance stand test was on a flat surface in a quiet area. All time-based fitness tests used a stopwatch to record the performance.

A tape measure was used (cm) and conducted in a flat area to record flexibility for sit and reach and standing long jump for power. Push-ups to measure the strength was also conducted on a flat surface and recorded according to the number of repetition (rep). The reaction time was measured through a stick-drop test using a ruler (cm) positioned on an armchair at a comfortable height in a quiet, well-lit testing area with no distractions. Finally, the coordination was measured by the number of hints in juggling tests using 3 balls in a designated testing area with enough space to juggle safely. All the tests were administered 3 times with an interval of 30 mins. in the same testing areas and select the best performance per test. A similar procedure was implemented during the post-tests.

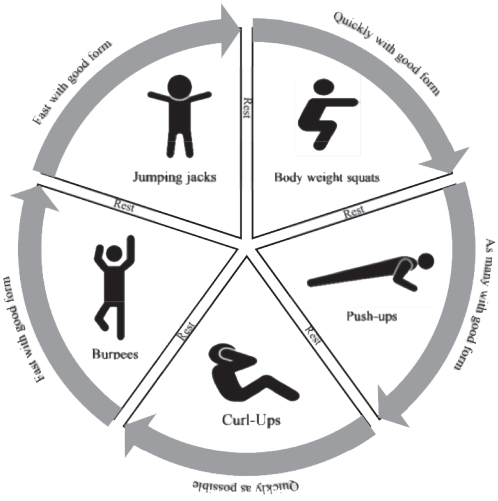

Fig. 1. Circuit training design

The 16-week interval progressive circuit training program was composed of 5 stations (Figure 1) with different intensities: jumping jacks (fast with good form), body weight squats (quickly with good form), push-ups (as many with good form), curl-ups (as quickly as possible), and burpees (as quickly as possible). The duration per station in the first week was 15 secs. and was increased by 5 secs. every 5 weeks. The number of sets per week started from 10 sets during the initial week and was increased by 1 set every 5 weeks. The rest per station in the first week was 10 secs. and was decreased by 1 sec. every 5 weeks (Table 2). In general, the interval progressive circuit training program of this study gradually increases the duration and sets while gradually decreasing the rest. The program also prioritizes proper form and gradually increases the intensity to minimize the risk of injury.

Table 2. Training program timeline

Weeks	1 to 5	6 to 10	11 to 15	16
Sets	10	11	12	13
Duration	15 secs	20 secs	25 secs	30 secs
Rest per station	10 secs	9 secs	8 secs	7 secs

Statistical Analysis

Data are presented as mean ± standard deviation for continuous variables and number (n) with percentage (%) for categorical variables. The Shapiro-Wilk test was performed to assess the normality of the distribution. To assess the difference between the pre-test and post-test, paired sample t-tests were used for normal data and Wilcoxon signed-rank tests for non-normal data. Statistical significance was accepted at $p \leq 0.05$. Cohen's d effect size (ES) was computed to display the magnitude of differences between variables and interpreted as trivial (0-0.19), small (0.20-0.49), medium (0.50-0.79), and large (≥0.80) (Cohen, 1988). Welch's t-test was used to compare the mean difference by sex and age. The statistical analysis was performed using IBM SPSS version 27 (IBM company, Armonk, New York, USA).

Results

The participants completed the 16-week training program with 100% attendance.

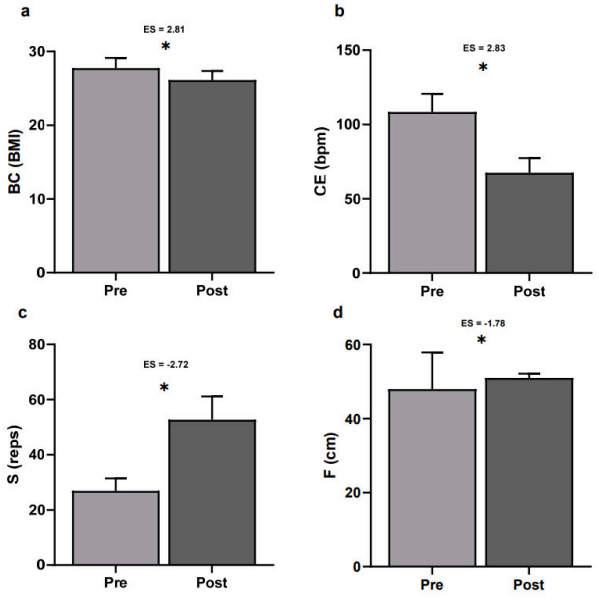

Fig. 2. Health-related fitness performance variables pre-and post-test
Abbreviation: BC, Body Composition; BMI, Body Mass Index; CE, Cardiovascular Endurance; bpm, beats per minute; S, Strength; reps, repetitions; F, Flexibility; cm, centimeter. * Indicated significant change comparing pre-and post-test. ES, Effect Size. p = 0.05

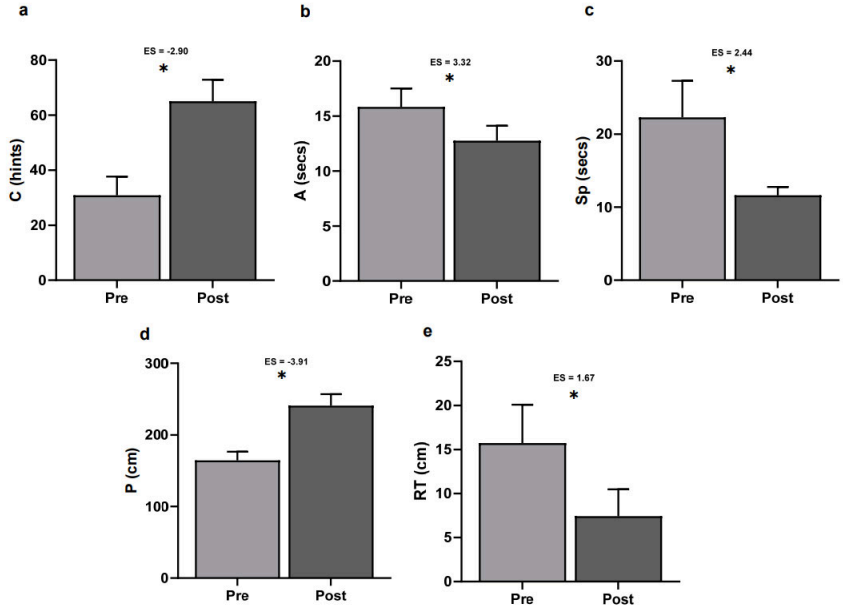

Fig. 3. Skill-related fitness performance variables pre-and post-test
Abbreviation: C, Coordination; A, Agility; secs., seconds; Sp, Speed; P, Power; cm, centimeters; RT, Reaction time.
* Indicated significant change comparing pre-and post-test. ES, Effect Size. p = 0.05

According to the results on health-related fitness performance, there was a significant decrease with a large effect size in BMI (27.74 ± 1.38 vs 26.11 ± 1.25 [n]; ES = 2.81) and cardiovascular endurance (108.35 ± 12.23 vs 67.42 ± 9.90 [bpm]; ES = 2.83), as well as increase with large effect size in strength (26.88 ± 4.54 vs 52.72 ± 8.42 [rep]; ES = -2.72) and flexibility (47.96 ± 9.89 vs 50.97 ± 1.16 [cm]; ES = -1.78) at p<0.05 (See Figure 2).

The performance in pre-and post-test results of skill-related fitness performance shows a significant increase with a large effect size in coordination (30.86 ± 6.83 vs 65.07 ± 7.81 [hints]; ES = -2.90) and power (164.36 ± 12.17 vs 240.78 ± 16.16 [cm]; ES = -3.91), as well as significant decrease with large effect size in agility (15.84 ± 1.67 vs 12.77 ± 1.35 [secs]; ES = 3.32), speed (22.30 ± 4.99 vs 11.61 ± 1.16 [secs]; ES = 2.44), and reaction time (15.72 ± 4.36 vs 7.44 ± 3.04 [cm]; ES = 1.67) at p≤0.05 (See Figure 3).

Discussion

My findings showed that the 16-week interval progressive circuit training program has a large effect on the physical fitness of the participants. In line with health-related fitness, there was a significant increase in strength and flexibility and a significant decrease in BMI and cardiovascular endurance. A significant increase in coordination and power and a significant decrease in agility, speed, and reaction time were also observed in skill-related fitness.

Health-related Fitness Performance

The decrease in BMI suggests that the overweight participants in my study showed improvement. Previous studies indicated that progressive training programs positively reduced weights (Čvorović et al., 2021; Arrieta et al., 2022). Although the mean score of the participants in the BMI post-test (Figure 2) was still included in the overweight category, it can be noted that the effect size was at large magnitude size. In applied terms, high-intensity workouts elevate heart rate and metabolic rate significantly during intense bursts of exercise (Grace et al., 2018). This increased intensity results in a higher calorie burn during the workout compared to lower-intensity exercises (Moro et al., 2020).

The decrease in bpm in the post-tests (Figure 2) shows a positive impact on the cardiovascular endurance of the participants. The gradual increase of reps. and sets of the training program trained the cardiovascular system of the participants to be more efficient at delivering oxygen-rich blood to the muscles during physical activity, allowing them to sustain exercise for longer periods without experiencing excessive fatigue or stress. This improved endurance can lead to various health benefits, including increased stamina, reduced risk of heart disease, and an overall improvement in their ability to engage in physical activities (Wibowo et al., 2022; Lan et al., 2021).

The increase in strength and flexibility with a large effect size shown in the post-test indicated a positive effect on the participants' skill-related fitness (Figure 2). The increase in strength may linked to the intensity of the workout and execution in the push-up station. While burpees station involves several dynamic movements that require the participants' joints and muscles to move through a range of motion. Kojić et al. (2021) in their experimental study, mentioned that burpees help improve joint flexibility over time, particularly in areas like the hips, knees, and shoulders. These improvements suggest that the training program of this study was successful in promoting muscle development and joint mobility. In addition, previous studies indicated that muscle development and joint mobility are essential components of a healthy and active lifestyle (Guldas et al.,

2023; Russo et al., 2021). It is worth mentioning that the intensity of the training program of this study helps the participants to improve their overall health-related fitness performance.

Skill-related Fitness Performance

A significant increase with a large effect size in coordination and power was also observed in the post-test (Figure 3). My findings underscore the substantial impact of the training program on participants' motor skills and explosive strength. It must be noted that the training program used in this study incorporates a mix of dynamic and strength-based exercises and provides a well-rounded approach to improving coordination and power. The combination of diverse movements, quick transitions, full-body engagement, and neuromuscular adaptations makes the training program an effective method for enhancing coordination and power (Cvetković et al., 2018; Kostikiadis et al., 2018; Laursen & Buchheit, 2019) of the participants.

A significant decrease with a large effect size was also shown in the post-test agility, speed, and reaction time performance of the participants (Figure 3). The effect is due to a dynamic blend of cardiovascular conditioning, strength development, neuromuscular coordination, and functional movement patterns gained from the training program. Studies have indicated that high-intensity training program promotes rapid force generation, improving explosive power and speed (Suchomel et al., 2018; Kunz et al., 2019). The incorporation of varied exercises challenges participants to transition swiftly, sharpening their reaction time. Meanwhile, the enhancement of neuromuscular coordination, core strength, and overall fitness contributes to greater agility (Sighamoney et al., 2018), enabling participants to move with precision and quickness.

In general, my findings suggest that the combination of diverse exercises, quick transitions, and neuromuscular adaptations in high-intensity circuit training can effectively enhance multiple aspects of physical performance. Therefore, future research may delve into the optimization of such training programs for specific groups and explore potential long-term health and performance outcomes for overweight individuals. Furthermore, investigating the sustainability and maintenance of these improvements over extended periods could provide insights into the long-term benefits of interval progressive circuit training programs. Finally, this research offers practical implications for fitness professionals and university students seeking to improve their physical fitness comprehensively, as it highlights the potential of well-structured high-intensity circuit training for achieving multifaceted fitness goals.

Conclusions

The study found that the 16-week interval progressive circuit training program positively affected various components of health and skill-related fitness among the participants. The findings underscore the versatility and effectiveness of high-intensity circuit training as a means of enhancing overall physical fitness, encompassing weight management, cardiovascular health, and skill-related attributes crucial for physical activities. The results of my study hold a valuable implication for fitness professionals, coaches, and individuals seeking well-rounded fitness enhancement. Additionally, my research encourages further exploration of optimized training protocols, long-term sustainability of improvements, and tailored applications for specific populations, ultimately advancing our understanding of the multifaceted benefits of interval progressive circuit training.

Conflict of Interest

The author declares that there is no conflict of interest.

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Вплив 16-тижневої програми прогресивного кругового тренування на показники стану здоров'я та фізичної підготовленості студентів університету з надмірною вагою

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 2 табл., 3 рис., 36 джерела.

Мета дослідження. Дослідження спрямоване на вивчення впливу 16-тижневої інтервальної програми прогресивного кругового тренування на фізичну підготовленість та стан здоров'я студентів університету з ожирінням.

Матеріали і методи. Загалом 72 студенти університету пройшли тестування на визначення стану здоров'я та фізичної підготовленості до і після 16-тижневої програми прогресивних кругових тренувань. Для визначення відмінностей між показниками до і після тестування було застосовано t-тести парних вибірок та критерій знакових рангів Уілкоксона.

Результати. Після проходження 16-тижневого прогресивного кругового тренування спостерігалося значне зниження показників ІМТ, витривалості серцево-судинної системи, спритності, швидкості та часу реакції ($p \leq 0,05$). Натомість показники сили, гнучкості, координації та результативності значно зросли ($p \leq 0,05$). 16-тижнева інтервальна програма прогресивного кругового тренування позитивно впливає на фізичну підготовленість учасників дослідження.

Висновки. Отримані результати спонукають до подальших досліджень оптимізованих тренувальних протоколів, довготривалої сталості покращень та адаптованих програм для конкретних груп населення, що в кінцевому підсумку поглиблює наше розуміння багатогранних переваг інтервального прогресивного кругового тренування.

Ключові слова: кругове тренування, фізична підготовленість, прогресія тренування, надмірна вага, студенти університету, стан здоров'я.

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Changes in High-Sensitivity C-Reactive Protein Levels After Two-Weeks of Moderate-Intensity Endurance Exercise in Obese Women

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Abstract

Study purpose. The study purpose was to analyze the effect of moderate-intensity endurance exercise on reducing inflammation in obese women.

Materials and methods. Twenty obese women selected according to the established criteria were used as subjects. Then the subjects were divided into two groups: the control group (G1) and the endurance exercise group (G2). Moderate-intensity endurance exercise was performed by running on a treadmill for 40 minutes, with a frequency of 5 times/week for 2 weeks. Moderate-intensity was performed with 60%-70% HRmax (HRmax formula: 220-age). Blood sampling for inflammation measurement using the biomarker High-sensitivity C-reactive protein (hs-CRP) was performed before and after the intervention for 2 weeks. hs-CRP was measured using the enzyme-linked immunosorbent assay (ELISA) method. A paired sample t-test with a significant level ($p \leq 0.05$) was used for data analysis.

Results. The results showed the mean hs-CRP levels between before and after the intervention in G1 (6.76±4.40 vs. 6.43±4.89 ng/mL, (p=0.641)) and G2 (6.56±3.34 vs. 2.12±1.14 ng/mL, (p=0.004)).

Conclusions. The study indicates that moderate-intensity endurance exercise has been shown to be effective in reducing inflammation levels in obese women, so individuals with obesity are advised to reduce inflammation levels through moderate-intensity endurance exercise.

Keywords: endurance exercise, inflammation levels, obesity, healthy lifestyle.

Introduction

Obesity is a multifactorial disease, that not only has an impact on the emergence of several diseases (Lin & Li, 2021) but also has an impact on risk factors for complications resulting from excess fat mass which can harm health. Obesity is associated with decreased expression of lipogenic markers leading to the development of metabolic complications, such as ectopic lipid deposition in skeletal muscle and liver (Moreno-Indias & Tinahones, 2015). This reduction has a broad effect on accelerating risk factors for inflammation and oxidative stress, as well as reducing overall muscle function (Straight et al., 2021). Reduced muscle function resulting from obesity will contribute to insulin resistance and cardiovascular disease (Van Der Kolk et al., 2019), thus worsening morbidity and mortality (Bozzola et al., 2023). This will harm human resources in the future. Physical exercise is believed to be a strategic method and therapy for obese conditions (Sugiharto et al., 2022). Physical exercise has been widely used to reduce inflammation, thereby preventing complications in obesity (Calcaterra et al., 2022). However, the effectiveness of physical exercise on inflammatory parameters in obesity is still a matter of debate.

Inflammation was found to be high in obese conditions (Khanna et al., 2022), which will have an impact on metabolic disorders, stress, and tissue dysfunction (Andersen et al., 2016). Metabolic disorders have a greater risk of metabolic syndrome, and inflammation is associated with leukocyte activation and dysfunction in metabolic tissues such as adipose tissue, liver, pancreas, and blood vessels (Sheridan et al., 2012). Meanwhile, the occurrence of tissue dysfunction will have an impact on the accumulation

of fat in primary lymphoid organs, which will damage tissue integrity associated with a large number of leukocytes and an inflammatory phenotype (Vucenik & Stains, 2012). This will increase the risk of developing type 2 diabetes mellitus and is likely to be the main distributor of complications (Longo et al., 2019). In addition, high levels of inflammation in obesity cause neuroinflammation which results in decreased cognitive function (Salas-Venegas et al., 2022) and motor abilities through changes in brain function and the musculoskeletal system (Wang et al., 2016). Therefore, appropriate strategies are needed to reduce risk factors for inflammation in obesity.

Preventing increased inflammation in obesity can be done by limiting calories and physical exercise. According to previous research, calorie restriction using intermittent fasting is considered to have a beneficial impact on reducing inflammation (Hills et al., 2019). However, it requires longer time and consistency and the results are only temporary (Yeoh et al., 2015). Previous research has shown that calorie restriction in humans has not been proven safe and effective for reducing inflammation in obese conditions (Kökten et al., 2021).

Previous research suggests that physical exercise can reduce inflammation, which is associated with a decrease in fat mass and an increase in muscle mass (Mika et al., 2019). However, appropriate physical exercise is still a matter of debate. Proven by research conducted by Zheng et al. (2019) physical exercise in the form of endurance exercise can reduce inflammation levels in a group of adult women. However, research conducted by Park & Nickerson (2022) stated that physical exercise in the form of endurance exercise could not change inflammation levels in a group of adult women. Other research also states that women who are obese tend to experience higher levels of inflammation than women who have a normal weight (Cohen et al., 2021). However, other studies show opposite results (Accattato et al., 2017). Therefore, The study purpose was to analyze the effect of endurance exercise on reducing inflammation using the biomarker High-sensitivity C-reactive protein (hs-CRP).

Materials and Methods

Participants

This study was a true-experimental with a pretest-posttest control group design. The study used 20 obese women as research subjects selected based on the following criteria: age 20-30 years, BMI 27-35 kg/m², blood pressure (systolic 110/120 mmHg and diastolic 70/80 mmHg), resting heart rate 60-80 bpm, oxygen saturation 96-100%, inactive in exercise, non-smoker, and non-alcohol consumer.

Study Design

Then, the subjects were divided into two groups, namely the control group (G1; n=10), and the endurance exercise group (G2; n=10). Endurance exercise was performed by running on a treadmill for 40 minutes, using moderate intensity (60%-70% HRmax) calculated by the formula (220-age). During endurance exercise, heart rate was monitored using POLAR H10. The entire research procedure was approved by the Research Ethics Committee Universitas Negeri Malang with the number 07.12.2/UN32.20.2.9/LT/2023.

Blood samples were taken to measure inflammation levels before and after endurance exercise intervention, taken from the cubital vein as much as 4 ml. Inflammation levels were analyzed using the ELISA method (Cat.No: E-EL-H0043; Elabsciencer Biotechnology Inc, USA).

Statistical Analysis

Data analysis was performed using the Statistical Package for the Social Science (SPSS) version 21.0. Data that were normally distributed and had homogeneous variance were analyzed using paired samples t-test and independent samples t-test with a significance level of 5%.

Result

Based on the study results, the data on the characteristics of the subjects in this study did not significant differences as presented in Table 1.

Table 1. Characteristics of research subjects

Variable	G1 (n = 10)	G2 (n = 10)	p-Value
Age, yrs	22.70±1.64	23.50±2.17	0.366
Systolic blood pressure, mmHg	113.05±6.19	115.25±3.49	0.344
Diastolic blood pressure, mmHg	70.08±5.66	72.65±7.73	0.407
Heart rate, bpm	76.80±7.87	75.80±3.74	0.723
Height, m	1.55±0.04	1.57±0.05	0.202
Weight, kg	71.04±4.55	73.02±7.99	0.507
Body mass index (kg/m²)	29.85±1.87	29.52±1.81	0.691

Based on the research results, there was a difference in the reduction in inflammation levels between the control group (G1) and the endurance training group (G2), this can be shown in the average reduction in inflammation levels in the control group (G1) and the endurance training group (G2) as in the Figure 1.

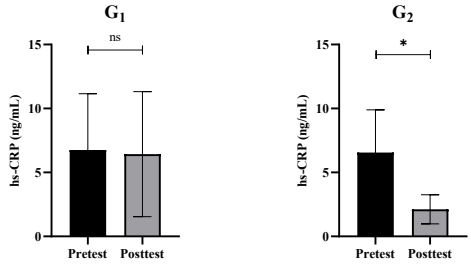

Fig. 1. Pretest and posttest hs-CRP levels (ng/mL) in both groups
Description: (*) The p-value indicates significant results at pretest ($p \leq 0.05$)

The results of the paired sample t-test mean pretest and posttest hs-CRP levels in the control group showed (6.76±4.40 vs. 6.43±4.89 ng/mL, p=0.641) and the endurance exercise group showed (6.56±3.34 vs. 2.12±1.14 ng/mL, p=0.004). These results show that the endurance exercise group significantly reduced inflammation levels, and the control group did not show a significant reduction.

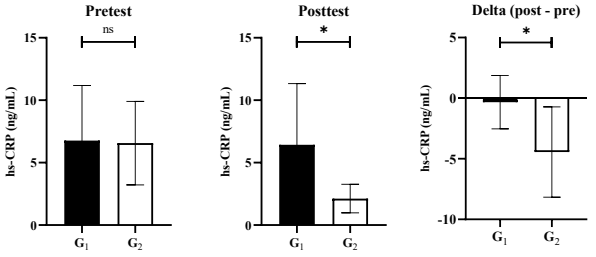

Fig 2. Pretest, posttest, and delta hs-CRP levels in both groups (G1 vs G2). Description: (ns) Not significant ($p \geq 0.05$). (*) Significant with a control group (G1) ($p \leq 0.05$)

Discussion

Obesity is often associated with inflammation which plays a role in the occurrence of complications (Marseglia et al., 2014), therefore it is important to reduce inflammation in conditions of obesity, one of which is endurance exercise. Based on the results of research that has been conducted, there is a difference in reducing inflammation levels between the control group (G1) of 0.33 ng/mL and the endurance training group (G2) of 4.44 ng/mL. The results showed a significant decrease occurred in the endurance training group (G2) compared to the control group (G1) (Table 1). The decrease in inflammation levels in (G2) was caused by endurance exercise. The endurance exercise used in this study reduced levels of circulating inflammation in the blood 2 weeks after exercise. These results are in line with research conducted by Fedewa et al. (2017) reported that endurance exercise can reduce inflammation >2 weeks after treatment. The results of previous research conducted by Gonzalo-Encabo et al. (2021) reported that endurance exercise can reduce inflammation levels in obesity cases.

This research involved subjects with obesity. In conditions of obesity, reducing body fat mass can improve mitochondrial function in adipocytes and reduce cytokine production which plays an important role in controlling inflammatory responses, endothelial function, and immunity (Bianchi, 2018). This can be proven in previous research conducted by Pranoto et al. (2023) reported that a decrease in inflammation occurred as a result of endurance exercise. Endurance training in this study is thought to increase anti-inflammatory activation which is influenced by increasing IL-10, IL-1RA, and sTNFr, thereby causing a decrease in inflammation such as IL-6, then IL-6 will increase the differential uptake of energy released in myocytes by increasing muscle insulin sensitivity and down-regulates inflammation (Kistner et al., 2022). These results are associated with research conducted by Leal et al. (2018) said endurance exercise can induce myocytes that can modulate adipose tissue to produce increased gene expression and secretion of IL-6, and there is an increase in IL-10, IL1-ra, and TNF-a, which is characterized as an anti-inflammatory effect.

The decrease in inflammation is thought to be due to the effects of endurance exercise. Muscle contractions caused by endurance exercise cause an increase in energy requirements using body fat by simulating lipolysis in adipose tissue, resulting in the release of free fatty acids (FFA) into the circulation and oxidation in the muscles (Mika et al., 2019) which can reduce the amount of fat mass in the body (Wedell-Neergaard et al., 2019). In addition, the reduction in inflammation is thought to be caused by the infiltration of immune cells such as macrophages which can be suppressed, and a phenotypic shift from M1 macrophages as inflammatory to M2 macrophages as anti-inflammatory which can be accelerated through endurance exercise (Saltiel & Olefsky, 2017). Macrophages activated via IL-10 indicate that M2 macrophages promote the early stages of proliferation myogenesis (Trendelenburg et al., 2012) which shows a change in macrophage phenotype during skeletal muscle regeneration with suppression of p38 MAPK signals followed by an increase in IL-10, so that it can work on M1 macrophage polarization to inhibit inflammation (Costamagna et al., 2015).

Endurance training can induce fatty acid metabolism through oxidation in muscle mitochondria to produce large amounts of ATP (Muscella et al., 2020) thereby triggering the activation of the adenosine monophosphate-activated protein kinase (AMPK) pathway which plays a role in conserving ATP by inhibiting the biosynthetic pathway and anabolic (glycogen and protein synthesis), as well as stimulating catabolic pathways by increasing glucose transport and fat metabolism (Egan & Zierath, 2013). Apart from that, endurance training can increase the number of mitochondria, an increase in mitochondria will cause biogenesis which will activate muscle cells by releasing myokines so that they can secrete irisin to increase energy expenditure by encouraging browning in white adipose tissue (Yano et al., 2021) and acts as an anti-inflammatory in the long term and helps restore inflammatory disorders in obesity conditions (Gonzalez-Gil & Elizondo-Montemayor, 2020).

The endurance training carried out in this study also paid attention to the intensity used because the subjects of this study were women with obesity. Endurance training performed at high intensity will result in major tissue damage and initiate excessive inflammatory and immunosuppressive reactions (Cavalcante et al., 2017). Meanwhile, endurance exercise performed at moderate intensity will reduce inflammation and increase fibrinolysis (Chen et al., 2014). Therefore, previous research recommends that moderate-intensity endurance exercise can reduce fat mass and reduce inflammation (Geliebter et al., 2015). Exercise intensity plays a role in determining the main energy source. The energy source used at high intensity will use the oxidation of carbohydrates, while at medium intensity the oxidation of FFA is more dominant. Therefore, this study was given endurance exercise with moderate intensity which is suitable for obesity conditions (Rejeki et al., 2023).

The results of this research can be used as a way to reduce inflammation levels in obesity through endurance exercise. However, this research has limitations, such as the research was only carried out on obese women, and endurance exercise was only carried out for 2 weeks so adaptation had not occurred. Therefore, it is recommended that further research be carried out on male subjects who are obese and in different age groups so that it can be generalized.

Conclusion

Based on research results, it was found that endurance exercise using moderate intensity (60%-70% HRmax) carried out for 2 weeks showed a decrease in inflammation levels in obese women, so this research recommends that individuals with obesity do endurance training consistently, taking into

account the intensity used. The results of this research can be used as a reference for future research by providing different exercise interventions and adding new parameters.

Conflict of Interest

The authors declares that there is no conflict of interest.

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Зміни показників С-реактивного білка високої чутливості після двох тижнів тренувань на витривалість помірної інтенсивності у жінок з ожирінням

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Реферат. Стаття: 7 с., 1 табл., 2 рис., 41 джерела.

Мета дослідження. Метою дослідження було проаналізувати вплив фізичних вправ на витривалість помірної інтенсивності на зменшення запалення у жінок з ожирінням.

Матеріали та методи. Об'єктом дослідження стали двадцять жінок з ожирінням, відібраних за встановленими критеріями. Потім досліджувані особи були розподілені на дві групи: контрольну (G1) та групу, що займалася фізичними вправами на витривалість (G2). Вправи на витривалість помірної інтенсивності виконувалися шляхом бігу на біговій доріжці протягом 40 хвилин, з частотою 5 разів на тиждень протягом 2 тижнів. Помірна інтенсивність виконувалася при показниках 60%-70% МЧСС – максимальної частоти серцевих скорочень (формула МЧСС: 220 – вік). Забір крові для оцінки запалення за допомогою біомаркера С-реактивного білка високої чутливості (hs-CRP) проводили до і після інтервенції протягом 2 тижнів. Показник hs-CRP визначали методом імуноферментного аналізу (ELISA). Для аналізу даних використовували t-критерій парних вибірок зі значущим рівнем ($p \leq 0,05$).

Результати. Отримані результати показали середні рівні С-реактивного білка високої чутливості до і після інтервенції в групах G1 (6,76±4,40 проти 6,43±4,89 нг/мл, p=0,641) і G2 (6,56±3,34 проти 2,12±1,14 нг/мл, p=0,004).

Висновки. Проведене дослідження свідчить про те, що фізичні вправи на витривалість помірної інтенсивності виявилися ефективними для зниження рівня запалення у жінок з ожирінням. Таким чином, особам з ожирінням рекомендується знижувати рівень запалення за допомогою фізичних вправ на витривалість помірної інтенсивності.

Ключові слова: фізичні вправи на витривалість, рівні запалення, ожиріння, здоровий спосіб життя.

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Stimulating Aerobic Energy Supply Reactions of Athletes in Rugby Union

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Abstract

Objectives. The study purpose was to evaluate the effectiveness of an experimental program of training means aimed at stimulating reactions of aerobic energy supply of athletes who are part of Ukraine national rugby union team.

Material and methods. The athletes of the Ukrainian national rugby union team were divided into two homogeneous groups (experimental and control) consisting of 15 individuals. The experimental group underwent a specialized program aimed at developing aerobic energy supply, whereas the control group followed a standard training program. The object of study focused on the training process of Ukraine national rugby union team.

Results. The results of testing rugby players in the experimental group demonstrated reliable changes in reactions of aerobic energy supply under the influence of a program of special training sessions. The most significant alterations were noted in the indicators of kinetics and stability of reactions. The indicators of O_2 consumption and pulmonary ventilation in the intensity zone of anaerobic metabolism threshold increased significantly. There was a tendency to increase indicators characterizing the power of the respiratory response (max V_E), in particular under conditions of growing fatigue (% excess V_E). However, there were no significant changes in indicators of aerobic capacities' components in the athletes' control group.

Conclusions. We believe that the mentioned indicators mostly reflect specialized manifestations of rugby players' aerobic capacities and impact the increase of athletes' special functional capabilities. This has been confirmed by the results of the analysis of urgent adaptive responses registered in model conditions of competition activity. As a result of the implementation of the specified experimental programme during the preparation process, the Ukrainian national team achieved 2nd place at the European Rugby Union Championship in the Trophy division of the 2022-2023 season.

Keywords: rugby, aerobic energy supply, cardiorespiratory system, experimental training program.

Introduction

To stimulate the reactions of aerobic energy supply, types of work in which the activity of the cardiorespiratory system is predominantly activated have been selected (Anderson & Drust, 2023; Miller et al., 2023). The pedagogical component of special training aimed at implementation of physiological stimuli of reactions involves definition of universal criteria for normalization of the load and assessment of its effectiveness. Universal criteria for normalization of the load may include the conditions for the development of cardiorespiratory system and the associated heart rate modes, reflecting the degree of activation (implementation) of a certain physiological stimulus or their complex use (Hulin et al., 2019; McHugh et al., 2019).

Heart rate criteria for control of response stimuli were applied when assessing the effectiveness of special motor activity. To develop the function of aerobic energy supply, operating modes in which the cardiorespiratory system is stimulated and exercises were selected with consideration to key factors of effective adaptation of rugby union athletes were systematized. The results of studies of the components of aerobic energy supply for athletes indicate that the key factors in the reduced aerobic potential of rugby players are expressed via an increase in the efficiency of the neurogenic mechanism. This factor includes an increase in the mobility of the nervous system as an activator of functional reactions of the body and resistance of the central nervous system to increasing fatigue (Grainger et al., 2022; Ahsan & Ali, 2023).

In this case, it is most advisable to use training tools aimed at implementation of a neurogenic stimulus and activation of a neurogenic stimulus under conditions of increasing fatigue. Activation of the respiratory response as a mechanism of respiratory compensation of metabolic acidosis. The analysis showed that to enhance the reaction of respiratory compensation of metabolic acidosis, modes of activation of an "acute" hypoxic stimulus are used in response to physical activity. Increasing the level of aerobic energy supply with no significant acidemic changes in the body (Périard et al., 2023). In this case, we are talking about activating the work of cardiorespiratory system due to the complex activation of neurogenic and acidemic stimulus reactions.

It should be noted that the use of conditions for the implementation of reaction stimuli in the process of functional training in rugby differs with the use of this approach in other sports (Briskin et al., 2016; Prystupa & Tyshchenko, 2017). These differences lie in the use of physical activity modes in which the level of glycolytic energy supply does not reach maximum levels at which the development of aerobic function stops. The work lasts for 5-12 minutes, within the period of predominant implementation of aerobic energy supply.

The criterion for this ability is the stability of the body's cardiorespiratory system. Consistent manifestations of the cardiorespiratory system can be assessed by the dynamics of the heart rate response. This universal criterion is accepted in sports practice as a way to assess changes in aerobic function during work.

The practical significance of this problem has become a prerequisite for conducting this study.

The purpose of the study is to check effectiveness of the experimental program of training means aimed at stimulating reactions of aerobic energy supply of athletes who are part of Ukraine national rugby union team.

Materials and Methods

Participants

The athletes of the Ukraine national rugby union team were divided into two homogeneous groups consisting of 15 people. One of them was experimental, the other was control. The experimental group completed an experimental program aimed at development of aerobic energy supply in one month, and the control group completed a regular training program. Prior to the testing, the procedures were explained to all of them, including possible risks involvement, and after the explanation, an informed consent form was signed. The experiment has been done after every participant was tested. The athletes were free from any injuries or neuromuscular disorder.

The study has been approved by the Institutional Ethics Committee, complied with all the relevant national regulations and institutional policies, followed the tenets of the declaration of Helsinki, and it has been approved by the authors' institutional review committee.

Methods and Procedures

The object of study is the implementation and effects of a training program designed to enhance aerobic energy supply reactions in National Rugby union athletes. This program aims to improve athletes' aerobic performance by focusing on the kinetics and stability of aerobic energy supply under conditions of increased fatigue and near the anaerobic threshold, with the ultimate goal of optimizing athletes' overall performance in competitive rugby union scenarios.

Changes in the reaction of the cardiorespiratory system of rugby players in the experimental group were registered as a result of assessing changes in power, stability and kinetics of the heart rate response. This reaction is an integral indicator of the changes in the cardiorespiratory system under the influence of training means. In addition, changes in this reaction are the most accessible and informative means of assessing changes in the aerobic function of the body when modeling competition activity in many sports (Hendricks et al., 2014; Meron & Saint-Phard, 2017; Lisenchuk et al., 2019), including rugby (Tyshchenko et al., 2018). To assess changes in reaction of rugby players in the experimental and control groups, the analysis of heart rate dynamics was carried out in the process of modeling the competition activity of rugby players. The rate of development of heart rate reaction was assessed under standard load conditions on a running ergometer for 6 minutes. The inclination angle of the treadmill was 0°, while the speed was 0.8 m/s^{-1}.

To standardize the measurements, the criteria of average heart rate were used, which corresponded to the level of maximum oxygen consumption (MOC) and the threshold of anaerobic metabolism (Barnes et al., 2021; Canda et al., 2023). For this purpose, changes in heart rate reactions were analyzed in regards to the intensity of work that took place in the zone of body's aerobic function maximization.

The ability of athletes to repeatedly achieve the reaction values of the cardiorespiratory system in the intensity zone close to the MOC was assessed. At the same time, the ability to repeatedly maintain stability of the reaction peak magnitude and the level of reaction in the intensity zone close to anaerobic metabolism threshold was assessed under the conditions of one match.

As a result of a contrastive analysis of the initial and final testing, differences in the reaction of the initial part of the experiment were obtained; the athletes noted an unstable heart rate at standard competition load. Rugby players achieved peak levels of cardiorespiratory response within a single match. However, the stability of this function has not been documented.

A tendency towards the function stability was noted only when reaching reaction intensity level at the level of anaerobic

Table 1. Orientation of the training process, reaction stimuli, characteristics of the load and conditions for the implementation of neurogenic, "acute" hypoxic and complex neurogenic and acidemic reaction stimuli (generalized data)

Targeted aerobic training	Reaction stimuli	Load conditions	Efficiency criteria
Increase of the efficiency of the neurogenic mechanism at the beginning of work	Neurogenic stimulus	Repeated, 5-second pace acceleration	Reaching peak heart rate response
Increase of the efficiency of the neurogenic mechanism in the process of growing fatigue	Neurogenic stimulus under conditions of growing fatigue	Increase of the pace for every 3 minutes of steady performance	Maintaining a steady heart rate response (sustainability of growth and stability during the period of uniform performance)
Activization of the respirator reaction as a mechanism of respiratory compensation of metabolic acidosis	"Acute" hypoxis stimulus	Linear 30-second increase and linear 30-second decrease in the work intensity for 60 seconds	Reaching and maintaining peak heart rate
Increase of the level of aerobic energy supply with no significant acidemic changes in the body	Neurogenic and acidemic stimulus (complex conditions of use)	–	–

metabolism threshold. Final testing of the rugby players from the experimental group showed significant changes in the reaction of the cardiorespiratory system in response to the experimental training program. The number of reaction peaks in different matches has increased. Stability of the peak values of the heart rate reaction during competition activity was noted. A linear nature of the increase in heart rate response should also be noted, which confirms the dominant influence of the work ensuring aerobic function.

At the same time, it is important to note the need to maintain levels of anaerobic glycolytic energy supply that do not affect inhibition of the nervous system and aerobic energy function of the body. The focus of special means of rugby players training, reaction stimuli and load characteristics in the process of implementing reaction stimuli are presented in Table 1.

The table presents generalized data for the application of conditions for the implementation of reaction stimuli in sports practice to ensure the work of target settings close to the tasks of aerobic training in rugby. The authors' work (Colosio et al., 2018; Pramkratok et al., 2022; Scott et al., 2022) provided the methodological and theoretical basis for our study.

The training program was based on modes of motor activity, which were aimed at sequential stimulation of neurogenic, "acute" hypoxic and acidemic stimulus reactions and on the use of the principle of sequential increase in load. The training program aimed at development of the aerobic energy supply function was carried out for one month (4 weeks). The program was based on motor activity modes aimed at sequential stimulation of neurogenic, "acute" hypoxic and acidemic reaction stimuli.

The principle of sequential increase in load was used. For this purpose, at the first stage of the program (1 week), during each session, athletes of the experimental group completed an amount of work that corresponded to body's optimal response to the load. The body's optimal response to load is associated with achieving and maintaining peak heart rate reaction values in response to an increase in work intensity, of intense training is associated with improved endurance performance (Hurley et al., 1984; Buchheit et al., 2009). The sessions were held in the morning, 1.5-2.0 hours before the main training. Functional training tools and performance efficiency criteria at the first stage are presented below.

The program for the first week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was preliminary activation of the cardiorespiratory system.

Days 1, 2, 3 of the first week – application of neurogenic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 1 minute. Duration of work is 6-8 minutes. The duration of work and the number of accelerations are dosed depending on the degree of increase in heart rate, achievement and maintenance of the peak reaction.

Days 4, 5, 6 of the first week – application of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. Part 2 – variable running: a combination of work at 40-50% of the maximum intensity level in combination with 15-second linear increase and linear decrease in the intensity of work every minute. Duration of work is 9-12 minutes. The duration of work and the number of accelerations are dosed depending on the degree of increase in heart rate, achievement and maintenance of the peak reaction.

At the first stage, sessions aimed at activation of acidemic stimulation of aerobic functions were not held.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

At the second stage (second week) of aerobic training of qualified rugby players from the experimental group, the volume of exercises required during the session was increased. This stimulated an increase in fatigue and the formation of an adequate reaction of the body. This could be observed by changes in heart rate dynamics during standard work.

Standard work was performed at an average heart rate level recorded for 3-5 minutes of steady work at the first stage. During the first and second days of sessions, work intensity was adjusted to optimize the load, at which a tendency to maintain the stability of the heart rate response during work was noted.

This is an important tool for activation of aerobic function and a criterion for assessment of work efficiency during the period of development of predominantly aerobic energy supply, provided that the body's glycolytic reactions are minimized (Weston & Gabbett, 2001).

The sessions were held before noon, taking into account the achieved effect of fatigue and the need to activate recovery processes; the chief training sessions were held in the afternoon in 3.5-4.0 hours. Functional training tools and performance criteria for the first stage are presented below.

The program for the second week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was targeted stimulation of the cardiorespiratory system.

Days 1, 2, 3 of the second week – application of neurogenic stimulation of the cardiorespiratory system.

Days 4, 5, 6 – application of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 15-second linear increase and 15-second linear decrease in the intensity of work in 1 minute. Series duration is 5 minutes. Number of series is 4.

At the second stage, sessions aimed at activating acidemic stimulation of aerobic functions were also not held.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

At the third stage (third week) of the aerobic training program for rugby players, long-term modes of steady work were additionally applied, in which stimulation of aerobic energy supply took place under conditions of increasing fatigue. Training sessions were held with focus on activation of acidemic stimulation of the cardiorespiratory system of rugby players.

The efficiency of stimulation of cardiorespiratory function as a result of the use of sequential implementation of neurogenic and acidemic stimulation of reactions is presented in scientific literature (Guo Pengcheng et al., 2020; Efremenko, 2010). The effect of increasing reactivity of the cardiorespiratory system on the next day, 20-24 hours after work, has been shown. Sessions were held from 10 to 11 o'clock in the morning. Taking into account the depth of impact of the load on the body, chief training sessions were held in the afternoon in 5.5-6.0 hours. Functional training tools and performance criteria for the first stage are presented below.

The program for the third week of aerobic training of qualified rugby players from the experimental group. The purpose of this research stage was stimulation of the cardiorespiratory system through the use of conditions for the implementation of neurogenic, "acute" hypoxic and acidemic reaction stimuli.

Days 1 and 2 of the third week – application of neurogenic stimulation of the cardiorespiratory system:

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration is 3 minutes. Number of series is 5.

Day 3 – neurogenic stimulation of the cardiorespiratory system under conditions of increasing fatigue

Part 1 – steady running for 5 minutes (warm-up). The intensity is 40-50% of the maximum level, selected individually. Part 2 – running at variable intensity for 12 minutes. 5-second maximum accelerations were done every 45 seconds of work.

Day 4, 5 – the use of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes (warm-up). Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 30-second linear increase and 30-second linear decrease in the intensity of work every 3 minutes of work. At the final stage (5-10 s) of 30-second linear increase in load, the intensity of work was maximum. Work time was 12 min.

Day 6 – the use of complex neurogenic and acidemic stimulation:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes. In three minutes, variable work (running) was done: a combination of work at a level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration is 5 minutes. Number of series is 2. Part 2 – steady running at the peak heart rate level (for 3-6 minutes of work), which was achieved as a result of performing accelerations in the first part of the session. Work time was 12 min.

Day 7 – rest. A long, one-hour walk in fresh air is recommended.

The fourth stage of the program. The fourth stage of the program lasted 12 days. These days included 9 days of experimental training sessions and 3 days to monitor changes in the athletes' performance. In this part of the aerobic training program for rugby players, additional blocks of training sessions were used, the duration of each block was 3 days. The goal of the stage was to achieve the maximum effect of increasing the aerobic function of the body due to the cumulative effect of using unidirectional means of performance stimulating for 3 days, and the cumulative effect of the training cycle. Sessions were held from 10 am to 12 pm.

The amount of special work of rugby players was reduced. Specific elements of rugby players training were worked out. Functional training tools and performance criteria for the first stage are presented below.

Days 1 and 2 (first block) – increase of the function of aerobic energy supply through the implementation of neurogenic stimulation of the cardiorespiratory system.

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart

rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration was 5 minutes. Number of series was 4.

Day 3 (first block)

Part 1 – steady running for 5 minutes (warm-up). The intensity was 40-50% of the maximum level, selected individually. Part 2 – running at variable intensity for 12 minutes. Maximum acceleration for 5 seconds was done every 45 seconds of work.

Day 4 – special work.

Days 5, 6, 7 (second block) – use of "acute" hypoxic stimulation of the cardiorespiratory system:

Part 1 – steady running (40-50% of maximum intensity) for 5 minutes (warm-up). Part 2 – variable running: a combination of work at a level of 40-50% of the maximum intensity level in combination with 30-second linear increase and 30-second decrease in the intensity of work every 3 minutes. In the final stage (5-10 s), 30-second linear increase in load; the intensity of work was maximum. Duration – 12 min.

Day 8 – special work.

Days 9, 10, 11 (third block) – complex use of neurogenic, "acute" hypoxic and acidemic stimulation of the cardiorespiratory system:

Part 1 – steady running for 5 minutes. Two times with a 3-minute rest interval. A correction was made to the work intensity in order to standardize the load at a steady heart rate level (±3 beats/min^{-1}) for 1.5-2.0 minutes of work. Part 2 – variable running: a combination of work at the level of 40-50% of the maximum intensity level with short-term 5-second accelerations in 30 seconds. Series duration was 5 minutes. Number of series was 4.

Day 12 – control measurements.

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 mean value (X) and standard deviation (s) of indicators of qualified rugby players were measured. The t-test was also used to compare indicators between the control group and experimental group (independent samples) and between groups before and after the experiment (paired samples). A significance level of 0.05 was used for the analyses. Before applying the t-test, a normality check of the data distribution was conducted.

Results

The results of the research made it possible to identify significant changes in the components of the aerobic energy supply of rugby players of Ukraine national rugby union team. In this context, the following key aspects and patterns regarding the influence of a specialized training program on the aerobic capacities of athletes can be identified.

The results of the analysis of changes in the rate of development of the cardiorespiratory system response are presented in Tables 2-4. As a result of the experiment, data have been obtained that made it possible to evaluate changes in the reactions of aerobic energy supply of rugby players. Changes in power, reactions stability kinetics, changes in the reaction of aerobic energy supply in the zone of anaerobic metabolism threshold were analyzed.

The experimental group demonstrated significant improvements in indicators characterizing aerobic capacity, namely maximum oxygen consumption (VO_2max), maximum lung ventilation (max V_E), percentage of excess ventilation (% excess V_E), time to reach 50% of max V_E ($T_{50}V_E$), time to reach a VO_2 plateau, indicating increased levels of aerobic function and oxygen use efficiency during intense exercise.

Thus, the experimental group showed a statistically significant increase in VO_2max by 5.2%, which indicates an improvement in aerobic power and endurance, which is critical for rugby players, since increased VO_2max improves overall physical performance and rapid recovery after intense exercise.

There was also a 4.8% increase in max V_E, indicating improved respiratory efficiency and body's ability to remove carbon dioxide and oxygenate blood during intense exercise more effectively.

Significant improvements in VO_2max kinetics, including a 7.3% reduction in time needed to reach 50% of max V_E ($T_{50}V_E$), indicate improved oxygen use efficiency and faster gains in aerobic power upon start of exercise.

Data show that the experimental training program facilitated a higher percentage of excess ventilation (% excess V_E), indicating better adaptation to aerobic workload as well as improved thermoregulatory mechanisms and oxygen metabolism.

One of the main outcomes of the training program was optimization of the response of the cardiorespiratory system to workloads approximated to maximum aerobic capacities of athletes. This demonstrates body's improved adaptation to high intensity and the ability to maintain high levels of physical activity without significant fatigue.

A significant increase in the rate of development of cardiorespiratory system reactions indicates an improvement in aerobic function. This is especially important in a competition environment, where the ability to quickly adapt to changing conditions and maintain high work intensity without significant fatigue can be a critical factor for success.

A significant increase in the effectiveness of aerobic potential under conditions of increasing fatigue was identified, which indicates an increase in endurance of athletes and their ability to maintain high level of energy supply for a long time, especially in critical phases of competition activity.

In the control group that followed a traditional training program, no significant changes in the components of aerobic capacity were noticed, which emphasizes effectiveness of using a specialized training program to improve aerobic capacity.

The hypothesis that the use of a specialized training program aimed at stimulating cardiorespiratory system helps to increase aerobic function of the body of Rugby union athletes has been confirmed. Effectiveness of the program was revealed in optimization of the heart rate response at workloads approaching the zone of maximum manifestation of the athletes' aerobic capabilities.

Table 2. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players during the experiment

N	Indicators	Registration conditions	Experimental group (n = 15)		Control group (n = 15)		Δx	t	Sig.	95% Confidence interval of the difference between the means	
			X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	before experiment	54.10	3.00	53.60	3.20	0.50	0.43	0.67	-1.819	2.819
		after experiment	54.90	1.10	54.00	1.10	0.90	2.16	0.04	0.077	1.723
2	max V_E (l/min)	before experiment	114.00	16.90	114.10	16.00	-0.10	0.02	0.98	-12.406	12.206
		after experiment	133.40	20.40	113.40	14.90	20.00	2.96	0.006	6.642	33.358
3	% excess V_E	before experiment	21.20	4.10	21.00	6.80	0.20	0.09	0.93	-3.999	4.399
		after experiment	24.90	2.80	20.90	4.10	4.00	3.01	0.005	1.375	6.625
4	$T_{50}V_E$ (s)	before experiment	31.90	8.90	32.00	12.70	-0.10	0.02	0.98	-8.301	8.101
		after experiment	24.70	9.10	32.90	11.20	-8.20	2.13	0.04	-15.831	-0.569
5	$T_{50}VO_2$, s	before experiment	35.00	9.60	34.60	9.90	0.40	0.11	0.91	-6.892	7.692
		after experiment	26.10	7.60	31.70	6.70	-5.60	2.07	0.047	-10.958	-0.242
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	before experiment	22.00	6.80	24.00	6.90	-2.00	0.77	0.45	-7.123	3.123
		after experiment	47.20	5.10	28.20	6.10	19.00	8.94	0.0001	14.796	23.204
7	V'_E TAM*, l·min^{-1}	before experiment	72.90	13.60	73.10	13.80	-0.20	0.04	0.97	-10.445	10.045
		after experiment	99.10	12.10	79.10	12.00	20.00	4.39	0.0001	10.989	29.011
8	$V'O_2$TAM ml·min^{-1}.kg^{-1}	before experiment	40.00	2.90	38.70	6.00	1.30	0.73	0.48	-2.224	4.824
		after experiment	45.20	2.00	41.30	6.00	3.90	2.31	0.03	0.556	7.244

* Threshold of Anaerobic Metabolism

Table 3. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players experimental group during the experiment

N	Indicators	Before experiment		After experiment		Δx	t	Sig.	95% Confidence interval of the difference between the means	
		X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	54.10	3.00	54.90	1.10	0.80	0.94	0.36	-0.890	2.490
2	max V_E (l/min)	114.00	16.90	133.40	20.40	19.40	2.74	0.011	5.392	33.408
3	% excess V_E	21.20	4.10	24.90	2.80	3.70	2.79	0.009	1.075	6.325
4	$T_{50}V_E$ (s)	31.90	8.90	24.70	9.10	-7.20	2.12	0.04	-13.931	-0.469
5	$T_{50}VO_2$, s	35.00	9.60	26.10	7.60	-8.90	2.72	0.011	-15.375	-2.425
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	22.00	6.80	47.20	5.10	25.20	11.09	0.0001	20.705	29.695
7	V'_E TAM*, l·min^{-1}	72.90	13.60	99.10	12.10	26.20	5.39	0.0001	16.574	35.826
8	$V'O_2$TAM ml·min^{-1}.kg^{-1}	40.00	2.90	45.20	2.00	5.20	5.52	0.0001	3.337	7.063

* Threshold of Anaerobic Metabolism

The findings prove the scientific comprehension of how specialized training programs can optimize aerobic capacity and overall physical performance of athletes in team sports such as rugby, where aerobic endurance and power play a key role in successful competition activity.

The implementation of the innovative training methodology aimed at optimization of kinetics of aerobic energy metabolism and maximization of functionality of cardiovascular and respiratory systems demonstrates statistically confirmed improvement in indices of maximum oxygen consumption (VO_2max), maximum lung ventilation (max V_E), as well as oxygen use efficiency at the level of kinetic characteristics of achieving VO_2max. These modifications of physiological parameters indicate a significant strengthening of

Table 4. Dynamics of indicators of aerobic energy supply reactions of qualified rugby players control group during the experiment

N	Indicators	Before experiment		After experiment		Δx	t	Sig.	95% Confidence interval of the difference between the means	
		X	s	X	s				Lower limit	Upper limit
1	VO_2max ml·min^{-1}·kg^{-1}	53.60	3.20	54.00	1.10	0.40	0.44	0.67	-1.389	2.189
2	max V_E (l/min)	114.10	16.00	113.40	14.90	-0.70	0.12	0.91	-12.261	10.861
3	% excess V_E	21.00	6.80	20.90	4.10	-0.10	0.05	0.96	-4.299	4.099
4	$T_{50}V_E$ (s)	32.00	12.70	32.90	11.20	0.90	0.20	0.84	-8.054	9.854
5	$T_{50}VO_2$, s	34.60	9.90	31.70	6.70	-2.90	0.91	0.38	-9.221	3.421
6	t VO_2(±2 ml·min^{-1}·kg^{-1}VO_2 "plateau"), s	24.00	6.90	28.20	6.10	4.20	1.71	0.11	-0.670	9.070
7	V'$_E$ TAM*, l·min^{-1}	73.10	13.80	79.10	12.00	6.00	1.23	0.24	-3.670	15.670
8	V'O_2TAM ml·min^{-1}.kg^{-1}	38.70	6.00	41.30	6.00	2.60	1.15	0.27	-1.887	7.087

* Threshold of Anaerobic Metabolism

adaptation processes in the body of athletes, which leads to an increase in their aerobic power and endurance, as well as to more effective recovery after high-intensity exercise.

Thus, the achieved results emphasize importance of an individualized approach in the development of training programs for high-level athletes, assuming the need for further research of the mechanisms of adaptation to aerobic exercise and their optimization to improve sports performance. These findings may serve as the basis for the development of innovative training strategies aimed at maximization of aerobic potential of athletes, which opens new horizons in sports medicine and physiology of higher nervous activity.

Discussion

Our research has confirmed the hypothesis that the use of a specialized program of training aids aimed at stimulating the cardiorespiratory system helps to increase the aerobic function of the body of the rugby union athletes. The effectiveness of the program has been manifested in the optimization of the heart rate (HR) response when performing loads close to the zone of maximum manifestation of the' aerobic capabilities of the athletes. These changes indicate an increase in the functional capabilities of the athletes, which, in turn, indicates the dominant influence of aerobic energy supply with a reduced influence of glycolytic processes.

As a result of the application of the training means program, it can be stated that the increase in the aerobic function of the body occurred due to the stimulation of the cardiorespiratory system of the body. This is evidenced by the optimization of the heart rate response under conditions of load intensity close to the zone of maximum manifestation of aerobic capabilities of athletes (Pastor et al., 2023; Waldron et al., 2023).

Optimization of the cardiorespiratory system is associated with an increase in the number of peak values of the heart rate response close to the level of MROC and an increase in the stability of the achieved levels of function during this period (Meir et al., 2023). Available tendency towards a linear increase of function indicates the dominant influence of aerobic energy supply under conditions of a reduced influence of glycolytic processes. These findings confirmed the results of changes in the rate of reaction development. A significant increase in the rate of development of rugby players' responses under the influence of special training means was noted.

The increase of functional capabilities of rugby players is shown by the increase of reactions that characterize various aspects of the aerobic potential of athletes, which is confirmed by Colosio AL et al. (Colosio et al., 2018). To a greater extent, these changes concerned those aspects of aerobic capabilities of athletes that influenced the performance of rugby players in the zone of anaerobic metabolism threshold and under conditions of growing fatigue in the process of competition activity.

An analysis of the structure of aerobic capabilities of qualified rugby players and its manifestations in the process of competition activity gives reason to state that activation of neurogenic, "acute" hypoxic and complex neurogenic and acidemic reaction stimuli can be a factor in improvement of functional capabilities of athletes (Pramkratok et al., 2022).

The results of using the program of training means aimed at stimulating the cardiorespiratory system of the body. The kinetics of the heart rate reaction has been analyzed. The initial part of the heart rate reaction, which was determined by the speed of development of the reaction has a close connection with the speed of development of aerobic energy supply reactions and objectively reflects the reactive properties of the cardiorespiratory system (Korobeynikova et al., 2018; Iso et al., 2023).

Increasing the speed of development of the cardiorespiratory system creates conditions for achieving peak reaction values, increases the share of economical aerobic energy supply in the overall energy balance to support performance of athletes (Rovniy et al., 2017; Diachenko, et al., 2020; Tyshchenko et al., 2020). An increase in the kinetics of reactions of the cardiorespiratory system is one of the objective indicators of a positive change in the function of aerobic energy supply as a response to special loads (Mishchenko et al., 2009; Sado et al., 2023). The use of conditions for the implementation of these reaction stimuli allows the development

of functions of the cardiorespiratory system with anaerobic glycolytic energy supply not been actively used in the work, which is a requirement for improvement of aerobic capabilities of athletes. Strengthening the role of these factors will enble to better form both mobilization and implementation components of endurance, in relation to specific conditions of body fatigue, in the process of competition activity of athletes in Rugby union (Naughton et al., 2023; Scott et al., 2022).

The use of the program has led to a significant increase in the speed of development of reactions of the cardiorespiratory system, which is an important indicator of improvement of aerobic function. This is especially important within the competitive conditions, where the ability to adapt quickly to changing conditions and maintain high intensity of work without significant fatigue can become a decisive factor for success.

The increase in functional capabilities in the anaerobic metabolism threshold zone has been also noted, which indicates an increased efficiency of aerobic potential in conditions of increasing fatigue. These results highlight the importance of aerobic fitness for the athletes participating in sports with high aerobic demands, such as Rugby union.

The multilevel analysis demonstrates how specific training interventions, including neurogenic and hypoxic stimulation, can optimize adaptive mechanisms of the cardiorespiratory system of athletes. This approach differs from traditional methods presented in previous researches (Rovniy et al., 2017), due to its ability to target specifically improvements in the metabolic efficiency and aerobic power of athletes, which represents a significant addition to the doctrinal provisions in the field of sports physiology. Our research expands the understanding of physiological adaptations to extreme training conditions and offers an innovative methodology for improving the functional performance of rugby players based on an integrated approach to the preparation process.

So Rovniy, A. et al. focused on the effect of normobaric interval hypoxic training, depending on the playing position of the players. We have added to existing knowledge by showing that a specific training program can lead to the significant improvements in aerobic performance and endurance of the athletes, which highlights the importance of an individualized approach to the preparation process in rugby.

The results of rugby players testing from the experimental group showed significant changes in the reactions of aerobic energy supply under the influence of a special training program. With athletes of the experimental group, the most significant changes were noted in terms of the kinetics and stability of reactions; the indicators of O_2 consumption and pulmonary ventilation in the intensity zone of the anaerobic metabolism threshold significantly increased. A tendency towards an increase in indicators that characterize the power of the respiratory response (max V_E), including the ones under conditions of increasing fatigue (% excess V_E) was observed. At the same time, no significant changes in the power of the O_2 consumption reaction (VO_2max) were observed. With the athletes of the control group, no significant changes in the indicators of the components of aerobic capacity were observed. The data presented indicate the development of aerobic capabilities in the zone of anaerobic metabolism threshold and an increase in the efficiency of aerobic potential realization under conditions of growing fatigue (McNeill et al., 2021).

The results suggest that rugby training imposes high aerobic demands, which may be too high in addition to strength training and therefore limit optimal endurance development (Chtara et al., 2005). These indicators largely reflect the specialized manifestations of the aerobic capabilities of rugby players and influence on the increase of special functional capabilities of athletes, as indicated by studies of high-level rugby players in China (Fu et al., 2019). The authors found that the aerobic power is different between the forwards and the defenders, but the power of aerobic of Chinese players is weaker than that of the foreign rugby players. This has been proved by the results of the analysis of urgent adaptive reactions recorded in model conditions of competition activity (Luginbühl et al., 2023; Twist & Highton, 2023). However, scientists found no effect of strength training on endurance performance (VO_2max) in studies of team sports players (Ignjatovic et al., 2011). The increase in the kinetics and stability of aerobic energy supply reactions and relatively reduced rates of increase in MROC are logical from the point of view of the direction of additional stimulating effects (Doma et al., 2019). To develop MROC, modes of motor activity of submaximal intensity and training sessions with a high load are usually used.

Our approach demonstrates an in-depth understanding of the specific physiological mechanisms underlying adaptations to rugby training, while the research by O'Gorman, D. Et al. emphasizes the value of using field tests to assess aerobic function (O'Gorman et al., 2000).

The results we have obtained stand out due to the understanding of aerobic adaptations of rugby players, adding to existing knowledge of physical fitness in the sport (Colosio et al., 2018; Fu et al., 2019).

In contrast to the generally accepted view of the predominant effect of anaerobic training on the performance of rugby players (Söyler et al., 2024), our research highlights the importance of aerobic training and its specific effect on improving aerobic capacity, especially in the anaerobic threshold zone, without a noticeable increase in maximum oxygen consumption. This expands the understanding of training approaches to improve endurance and aerobic performance of high-level athletes (Chtara et al., 2005; Doma et al., 2019; Booth et al., 2020).

We also emphasize the importance of aerobic fitness to improve the performance capabilities of rugby players. The scientists have confirmed that aerobic fitness plays a key role in improving endurance on the rugby field, and includes the development of aerobic power (Gabbett, 2005) and lactate tolerance (Gabbett, 2006; Hurley et al., 1984; Taylor et al., 2021), which is crucial for effective recovery from anaerobic efforts in the game.

The experts emphasize the importance of aerobic endurance for improving gaming performance. Aerobic power and lactate tolerance are key components needed to maintain high levels of energy production during play and recovery from anaerobic efforts. It is suggested the use of various training methods such as steady tempo (Rennie et al., 2021; Gabbett & Masters, 2011), interval training (Tian, 2022; Vachon et al., 2022) and special endurance (Camillini et al., 2018; Senavirathna et al., 2021), to develop these components, which complements our research on aerobic adaptations in rugby.

We have described the use of specialized training programs to achieve improvements in aerobic performance

of rugby players. The authors confirm that various training methods are used to develop aerobic endurance, including interval training and specialized exercises that simulate real-life match conditions (Pastor et al., 2023) It is indicated that training approaches can vary significantly and must be adapted to the specific needs of athletes, as stated by a number of experts (Mellalieu et al., 2023; Fazackerley et al., 2023).

Our research focuses on the fact that aerobic demands may differ depending on playing position. Similar findings have made by a team of specialists that considered the physiology of aerobic exercise of professional rugby players, where it has been found that attackers and defenders have different levels of aerobic fitness (Hu et al., 2022; Hart et al., 2023), highlighting the need for individualized training programs (Zabaloy et al., 2020; Scott et al., 2023; Taylor et al., 2021).

Our article is complemented and supported by the findings of the specialists, regarding the effects of aerobic training on rugby players. Thus, a study conducted by Julien Robineau and his colleagues shows that recovery between strength and aerobic training affects adaptation to combined training (Robineau et al., 2016). They found out that training without a break between strength and aerobic sessions (C-0h), and to a lesser extent, training twice a day (C-6h), was not optimal for improving neuromuscular and aerobic performance, highlighting the importance of planning the preparation process to achieve full adaptive response to combined training. We have added to existing knowledge demonstrating that a targeted combination of specific stimulation can improve effectively the aerobic performance of rugby players, suggesting new techniques for enhancing athletic performance, while the reviewed study by Julien Robineau et al. highlights the importance of recovery time between strength and aerobic sessions to maximize increase in strength and aerobic performance power.

We have presented an innovative approach to the preparation process of rugby players, including neurogenic and hypoxic stimulation to improve aerobic capacity. Unlike previously studied methods by the Scott, A.C. et al., where they emphasized on assessing the aerobic physiology of professional rugby players through standardized maximal oxygen uptake tests, our approach adds to existing knowledge by providing a technique that not only increases aerobic performance indicators, but also maskes this with the help of specific, targeted stimulation. This provides additional training opportunities based on physiological adaptations to exercise, increasing understanding of how rugby performance can be effectively improved (Scott et al., 2003).

Thus, our research and information from other specialists complement each other, emphasizing the importance of aerobic training in rugby, confirming that aerobic training should take into account the specifics of the sport, playing positions and individual characteristics of athletes to achieve optimal results.

Our research contributes to the specialized field of sports science by introducing an innovative approach to training for rugby players, focusing on the endogenous stimulation of cardiorespiratory adaptation through a synergistic combination of neurogenic activation and controlled hypoxic exposure. This methodology opens up the new perspectives for optimizing the physiological potential of athletes, providing an evidence base for the effectiveness of managing the adaptive reactions of the body under conditions of variable oxygen content, which, in turn, helps to increase aerobic capacity and improve the overall endurance of athletes at a highly competitive level.

Our research makes a significant contribution to the field of sports science by focusing on optimizing aerobic function of rugby players through tailored training approaches. It demonstrates how systematic stimulation of the cardiorespiratory system using neurogenic, "acute" hypoxic and acidemic stimuli can effectively increase the kinetics and sustainability of aerobic energy supply responses without causing significant acidemic changes in the body. This highlights the importance of integrating such training regimens into preparatory programs to improve the specific functional capabilities of rugby players, especially in the context of increasing aerobic capacity and performance under increasing fatigue conditions. The practical significance of the research lies in its potential to serve as the basis for the development of training programs that specifically influence the improvement of gaming endurance and general physical fitness of the athletes, which can directly affect their sporting achievements at the professional level.

Activation of neurogenic, "acute" hypoxic and acidemic stimuli through a specially designed training program has provided positive effects on aerobic capacity and fatigue resistance of the Rugby union athletes. These findings can be used to further development training methods aimed at improving athletic performance.

Due to the introduction of our experimental program in the preparation process, the Ukrainian national team eventually took 2nd place at the European Rugby union Championship in the Trophy division of the 2022-2023 season.

Conclusions

The study's conclusions of the study affirm the effectiveness of a specially devised training program aimed at augmenting the aerobic energy system's responsiveness in rugby union athletes. Through methodical application, the program significantly enhanced athletes' aerobic capacities, particularly under conditions straddling the anaerobic threshold and elevated fatigue levels. This was evidenced by the experimental group's superior performance metrics in comparison to a control group adhering to conventional training paradigms. These findings not only underscore the potential for tailored training interventions to optimize aerobic performance but also highlight their pivotal role in elevating competitive prowess, as exemplified by the Ukrainian National Rugby union team's accomplishments at the European Championship.

The prospects for further research in this field should focus on the longitudinal assessment of the training program's impact on the athletes' performance across multiple competitive seasons. Investigating the program's adaptability and effectiveness across different athletic disciplines could also yield valuable insights. Additionally, exploring the psychological aspects of endurance and performance under stress, as well as the integration of technology and data analytics for personalized training regimes, could further enhance the understanding and application of aerobic energy system optimization in sports.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

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Стимуляція реакцій аеробного енергопостачання спортсменів у регбі-15

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Реферат. Стаття: 13 с., 4 табл., 58 джерел.

Мета дослідження – перевірити ефективність експериментальної програми тренувальних засобів, спрямованих на стимуляцію реакцій аеробного енергозабезпечення спортсменів, які входять до складу національної збірної України з регбі-15.

Матеріал і методи. Спортсмени збірної України з регбі-15 були розподілені на дві однорідні групи (експериментальну та контрольну) по 15 осіб. Експериментальна група займалася за розробленою програмою, що спрямована на розвиток аеробного енергозабезпечення, тоді як контрольна група – за стандартною програмою тренувань. Об'єкт дослідження – навчально-тренувальний процес національної збірної України з регбі-15.

Результати. Результати тестування регбістів експериментальної групи продемонстрували достовірні зміни реакцій аеробного енергозабезпечення під впливом програми спеціальних тренувань. Найбільш суттєві зміни відзначені в показниках кінетики та стійкості реакцій, достовірно підвищилися показники споживання O_2 та легеневої вентиляції в зоні інтенсивності порогу анаеробного обміну. Спостерігалася тенденція до підвищення показників, що характеризують потужність дихальної реакції (max V_E), зокрема в умовах наростаючої втоми (% перевищення V_E). У спортсменів контрольної групи суттєвих змін показників компонентів аеробних можливостей не було.

Висновки. Вважаємо, що зазначені показники здебільшого відображають спеціалізовані прояви аеробних можливостей регбістів, і впливають на підвищення їх спеціальних функціональних можливостей, що підтверджено результатами аналізу термінових адаптаційних реакцій, зареєстрованих у модельних умовах змагальної діяльності. Результатом реалізації зазначеної експериментальної програми в процесі підготовки стало ІІ місце збірної України на Чемпіонаті Європи з регбі-15 у дивізіоні Трофі сезону 2022-2023 років.

Ключові слова: регбі, аеробне енергозабезпечення, кардіореспіраторна система, експериментальна тренувальна програма.

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Unravelling the Relationship between External Load and the Incidence of Hamstring Injuries in Professional Soccer Players

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

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Abstract

Objectives. The study aimed to analyze external load indicators with the incidence of non-contact hamstring injuries.

Material and methods. A non-experimental correlative, retrospective cohort study was carried out. The data were collected from 31 professional male soccer players over the course of one season. The following load indicators were examined: duration (D), total distance travelled (TDT), distance travelled at high intensity (DTHI) > 20 km/h, number of efforts between 20-25 km/h (NE 20-25 km/h), distance travelled at more than 25 km/h (DR+25 km/h), number of sprints greater than 25 km/h (NE > 25 km/h), number of accelerations greater than 1 m/s^2 (Acc), and number of minor decelerations at -1 m/s^2 (Dcc). Only non-contact hamstring injuries were included in the analysis. For the multivariate analysis, we applied a logistic regression model, where a value of $p < 0.05$ was established both for the statistical significance of the model (X^2) and for each of the regressor variables (X^2), the confidence interval level was 95%.

Results. Two injuries were recorded and diagnosed: injury grade 2 and muscle fatigue. The load indicators analyzed did not show a significant correlation with hamstring injury. Therefore, no association was found between external load and hamstring injury in professional soccer players.

Conclusions. The logistic regression model ($p > 0.05$) did not present statistical significance. Consequently, none of the external load variables monitored explain the rate of non-contact hamstring injuries in this population.

Keywords: external load indicators, hamstring injury, global positioning system (GPS).

Introduction

For García Romero (2022), in high-level sport, the physical and psychological requirements are essential; to evaluate them, different types of monitoring of athletes are carried out to assess their capacity to assimilate loads and their state of recovery to be able to face training. or a match. In Soccer, the need to evaluate the player correctly means that different markers are analyzed to identify the player's status to compete at the highest level of his/her ability. According to Barnes et al. (2014) Soccer has become a much faster, more intense and more competitive game, with physical and technical demands that have increased significantly. Newton et al. (2019) consider that the player must prepare for the high physical demands that arise in training and matches. Wallace et al. (2014) indicate that the external load is the work done by the athlete in variables such as distance traveled, number of sprints, accelerations, decelerations. According to Gabbett (2016), this load refers to the athlete's locomotor movements that can be monitored and measured with global positioning systems (GPS). This being an instrument of validity and reliability (Casamichana et al., 2013), approved by the Federation International Football Association (FIFA, 2015). For Halson (2014), training load monitoring has become a modern scientific approach that allows us to better understand athletes' training responses and preparation for competition. Rago et al. (2019) suggest that this technological advance allows optimization of the monitoring, control and quantification processes of the load in training and competition. Jaspers et al. (2016) indicate

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that tracking and monitoring the load allows optimizing training processes and planning strategies for injury prevention. Gabbett & Domrow (2007) state that a correct balance between training and competition load with optimal recovery is essential to achieve maximum performance and of great importance in injury prevention. Baztán (2018) states that one of the most frequent injuries in soccer is the hamstring, the most common injury mechanism being linear sprinting at maximum speed, presenting the highest injury incidence at the end of matches, which raises suspicion of the fatigue as a risk factor for injury in soccer. On their behalf, Garrett et al. (1984) state that this muscle group has the capacity to produce large forces, having an impact on actions such as: accelerations, decelerations, high-speed actions and changes of direction. Ekstrand et al. (2011) found that 12% of the injuries recorded during a season occurred in the hamstrings, generating approximately 80 days of absence, in addition to the economic cost that this implies. According to Ekstrand et al. (2022) in recent seasons hamstring injuries have increased, the authors described the injury incidence in professional soccer players during 21 seasons (2001/02 to 2021/22). There were 2,636 hamstring injuries, which represented 19% of all reported injuries. The proportion of injuries increased from 12% during the first season to 24% in the most recent season. In this same period, the percentage of days of absence due to said injury increased from 10% to 20%. Raya & De la Torre (2018) highlight the importance of quantifying the load to improve performance and reduce injuries. Knowing the individual demands in training allows us to identify if the player manages to reproduce the demands in competition, important information for the coaching staff in the application of specific stimuli and work that can cover the demands of each athlete. Jaspers et al. (2018) demonstrated that load indicators, mainly external ones, are associated with a greater or lesser risk of injury, recommending the monitoring of different load indicators for the prevention of injuries in professional soccer.

Objective. Determine the association of external load with the incidence of hamstring injuries in professional soccer players.

Hypothesis. Null hypothesis (Ho): There is no association between external load and the incidence of hamstring injuries in professional soccer players. Alternate hypothesis (Ha): There is an association between external load and the incidence of hamstring injuries in professional soccer players.

Material and Methods

Participants

Thirty-one professional soccer players (age 25.2 ± 4.8 years, weight 77.0 ± 7.8 kg, height 181.1 ± 8.3 cm, BMI 23.4 ± 1.6 kg/cm^2) participated in the present study. The ethical aspects promulgated in the Declaration of Helsinki for research in human beings were taken into account, as well as the provisions of Resolution 8430 of 1993 of the Ministry of Health of Colombia, and in accordance with it the study is classified as having minimal risk for the subjects. All agreed to participate in the study, which was protocolized by signing the informed consent. The endorsement of the ethics committee of the University Institute of Physical Education and Sports at the University of Antioquia was obtained through document No. 069 of December 14, 2020.

Data Collection

It was carried out following the guidelines for GPS data collection and processing. All training sessions and matches were individually quantified using 10 Hz GPS technology (Catapult – OptimEye S5). For Scott et al. (2016) the GPS is an instrument independently validated in more than 100 peer-reviewed scientific journals worldwide. This sampling frequency has demonstrated validity and reliability for high movement demands at high intensity in team sports. The selected external load indicators were: duration (minutes), total distance traveled (m), distance traveled at high intensity (>20 km/h, equivalent to 5.56 m/s) (m), number of efforts 20-25 km/ h, distance traveled (+25 km/h, equivalent to 6.94 m/s) (m), 30 m sprints between 6-7 m/s^2, number of accelerations (>1 m/s^2) and number of decelerations (<– 1 m/s^2).

The injuries were diagnosed and recorded by members of the professional soccer club's medical staff. Following the recommendations of Fuller et al. (2006) data collection procedures were carried out in accordance with the consensus statement for soccer injury studies endorsed by the FIFA Medical Assessment and Research Centre, coding each diagnosis by location, type and mechanism of injury (traumatic or overuse). The study recorded non-contact hamstring injuries during the 2021-1 season. It is worth noting that the data were collected during the global pandemic derived from COVID-19, which probably could have generated alterations in the conditional expression of the soccer players (both in training and in competition).

Design and Procedures

A non-experimental correlative retrospective cohort study was carried out on thirty-one professional soccer players during the 2021-1 season. 145 training sessions and 26 games were monitored.

The information on the external load was collected by the club's performance analyst using GPS; for the field training sessions, he placed the devices on each player in their respective vests before starting the activities, which were identified with the competition jersey number, subsequently verifying that each of these were being registered correctly. Data were monitored and recorded for each period during the training session. Recovery times were not included. At the end of the last period, the devices were turned off and collected for later downloading data to the software (Catapult OptimEye, S5). For the matches, the same procedure used in training was applied to the selected players; they turned on when they went out to warm up, at the end of the match they turned off and they were collected for the subsequent download of data.

Hamstring overuse injuries during the 2021-1 season were diagnosed and recorded by the club doctor after analyzing the MRI results, confirming the diagnosis of hamstring muscle tear and evaluating which muscle was affected and the extension that presented such tear. Each diagnosis was characterized by its location, type, mechanism of injury, time of injury, training or match, and days of

disability. The previous information was sent by the club doctor to the performance analyst and the latter to the main researcher to update data on the event that occurred.

Statistical Analysis

The information collected was recorded and stored in an Excel spreadsheet. Once the quality of the information had been refined and reviewed, it was exported for its respective analysis in the SPSS V.27 and RStudio V.4.0 programs.

For the exploratory analysis, descriptive statistics were used (mean, median, standard deviation, coefficient of variation and interquartile range) depending on the type of distribution of the variables, which was established from the Shapiro-Wilk test. For the correlative and association analysis between variables, the chi-square, Pearson's r, Spearman's r and point biserial correlation coefficient tests were used, which depended on the type of variables to be related. For the multivariate analysis, a logistic regression model was used, where a value of $P<0.05$ was established both for the statistical significance of the model (X^2) and for each of the regressor variables (X^2), the interval confidence level was 95%.

Results

Table 1 indicates the general profile of the external load indicators per training session of the team, minimum, maximum and percentiles.

Table 2 reveals the descriptive statistics referring to the external load regressor variables in competition during the 2021-1 season.

Table 3 describes the statistical results for the different external load indicators by position in competition, where the longest duration (playing time) occurred in the goalkeeper position; the greatest total distance traveled was on the midfielders; In the lateral position, the maximums are reflected in what corresponds to the total distance traveled at high intensity, efforts between 20-25 km/h, the distance traveled at more than 25 km/h, number of sprints and number of accelerations. Finally, the greatest number of decelerations in the central position.

The external load indicators analyzed did not present any significant correlation with hamstring injury, therefore, no association of load with non-contact hamstring injury was found. However, the load presents a positive correlation between the different indicators, revealing that the non-contact hamstring injuries that occurred during the season were possibly due to other factors (table 4).

Table 2. Descriptive statistics referring to the competing external load variables (regressors)

Variables	Statistical	Results
D (playing time) (min)	Mean	64
	S.D.	22
DTR (m)	Mean	5740
	S.D.	1963
DTRAI 20-25 km/h (m)	Mean	267
	S.D.	135
Esf. 20-25 km/h (No.)	Mean	20
	S.D.	11
DTR +25 km/h (m)	Median	117
	Interc range	107
Sprints >25 km/h (No.)	Median	6
	Interc range	6
Acc. >1 m/s^2 (No.)	Median	14
	S.D.	5
Des. <-1 m/sec^2 (No.)	Median	16
	Interquartile range	10

(D) Duration (min), (DTR) Total distance traveled (m), (DTRAI) Total distance traveled at high intensity 20-25 km/h (m), (E) Efforts between 20-25 km/h, (DTR) Total distance traveled at more than 25 km/h (m), (Sprints) 30 m between 6-7 m/s^2, (Acc.) Number of accelerations (>1m/s^2), (Dcc.) Number of decelerations (<−1 m/s^2)

During the season, two players presented with a non-contact hamstring injury, with a diagnosis of grade two injury and muscle fatigue, generating 47 and 10 days of disability, in the lateral and winger positions respectively. The stepwise model discards the regressor variables; none of them are able to predict the probability of occurrence with the hamstring injury (Table 5).

The logistic regression model ($p<0.05$) did not present statistical significance (Table 6), consequently, none of the monitored external load regressor variables explains the rate of hamstring injuries in this population.

Table 1. General load profile per training session

		D (min)	DTR (m)	DTRAI (m)	E 20-25 km/h (No.)	DTR +25km/h (m)	Sprints (No.)	Acc. (No.)	Dcc. (No.)
Minimum		31.3	1200.6	23	0.3	0.8	0.2	6.4	8.8
Maximum		78.0	5810.4	214.1	15.8	115.5	6.0	25.5	54.2
Percentiles	25	52.7	2899.0	60.4	5.2	13.3	0.8	11.3	13.7
	50	56.0	3873.6	89.6	7.0	22.5	1.6	14.3	19.6
	75	65.0	4188.1	121.9	10.8	43.1	2.8	17.3	27.9

(D) Duration (minutes), (DTR) Total distance traveled (m), (DTRAI) Total distance traveled at high intensity 20-25 km/h (m), (E) Efforts between 20-25 km/h, (DTR) Total distance traveled at more than 25 km/h (m), (Sprints) 30 m between 6-7 m/s^2, (Acc.) Number of accelerations (>1m/s^2), (Dcc.) Number of decelerations (<−1m/s^2)

Table 3. External load indicators in competition by position

Position	N	Statistical	D (min)	DTR (m)	DTRAI 20-25 km/h (m)	Esf. 20 and 25 km/h (No.)	DR (+25 km) (m)	Sprints (No.)	Acc. (No.)	Dcc. (No.)
Goalkeeper	2	Max.	97.8	4201	58	7	15	1	12	13
		Min.	71.3	3520	12	1	2	0	8	13
		Mean	84.6	3860	35	4	8	1	10	13
		S.D.	18.7	481	33	4	9	1	3	1
Central	5	Max.	89.1	8104	450	38	298	16	18	47
		Min.	39.9	3329	118	9	61	3	11	12
		Mean	73.9	6448	291	23	155	8	14	25
		S.D.	20.0	1918	148	12	92	5	3	13
Winger	5	Max.	87.8	8257	554	44	381	19	21	32
		Min.	17.0	1818	123	10	69	4	0	0
		Mean	54.2	5315	315	25	195	10	12	17
		S.D.	26.3	2394	176	14	140	7	8	12
Midfielders	7	Max.	94.8	8925	478	38	211	12	23	29
		Min.	34.0	3266	94	8	0	0	7	11
		Mean	69.4	6830	297	21	96	5	16	18
		S.D.	21.3	1928	122	10	71	4	6	6
Wing Forward	5	Max.	79.3	7755	345	26	242	12	16	22
		Min.	30.4	2991	116	7	39	2	9	6
		Mean	50.5	4983	262	19	142	7	12	14
		S.D.	20.4	1925	94	8	76	4	3	7
Forward	3	Max.	71.1	6135	253	19	132	7	18	17
		Min.	36.7	3907	207	15	79	4	9	15
		Mean	57.2	5241	235	17	97	5	14	16
		S.D.	18.1	1178	25	2	30	2	5	1

(N) Quantity, (Est.) Statistics, (D) Duration (min), (DTR) Total distance traveled (m), (DTRAI) Total distance traveled at high intensity 20-25 km/h (m), (E) Efforts between 20-25 km/h (N°), (DTR) Total distance traveled at more than 25 km/h (m), (Sprints) 30 m between 6-7 m/s^2, (Acc.) Number of accelerations (>1 m/s^2), (Dcc.) Number of decelerations (<−1 m/s^2)

Discussion

The objective of the study was to determine the association of different external load indicators with the incidence of non-contact hamstring injuries in professional soccer players. Verstappen et al. (2021) in their systematic review took into account the evaluation of external load parameters: duration, total distance traveled, high-speed running and acceleration, they did not find sufficient evidence or significant correlation of association between training load and injury risk in elite youth soccer players. and that non-contact muscle injuries may have possibly been due to other factors. Similar results were obtained in the present study in which similar external load indicators were analyzed, which did not present an association with non-contact hamstring injury.

Jaspers et al. (2018) demonstrated that load indicators, mainly external ones, are associated with an increase or decrease in the risk of injuries. On the contrary, for this investigation the results demonstrated that the external load indicators do not present an association with the risk of non-contact hamstring injury. Likewise, Jaspers et al. (2018) analyzed data from 35 male professional soccer players during two seasons (2014-2015 and 2015-2016), recording 64 overuse injuries. For 21 consecutive seasons Ekstrand et al. (2022) collected data from 3909 players from 54 teams (in 20 European countries) from 2001/02 to 2021/22, concluding that the proportions in hamstring injuries in number of injuries and days of total absence doubled during the study period. Additionally, they found that over the past eight seasons, hamstring injury rates increased in both training and matches. The season analyzed in this study was carried out with a single team during the 6-month season (2021-1), recording 2 non-contact hamstring injuries.

The professional soccer club under research for the 2021-1 season presented a low non-contact hamstring injury rate, reaching the final stages of the championship. In a study

Table 4. Correlation of external load indicators with non-contact hamstring injury

External load indicators		D (min)	DTR (m)	DTRAI 20-25km/h (m)	Esf. 20 and 25 km/h	DR (+25km/h) (m)	Sprints	Acc.	Dcc.	Hamstring injury
D (min)	Coef. corr.	1.000	0.688 **	0.428 *	0.450 *	0.319	0.390 *	0.627 **	0.231	0.220
	Sig. (bil.)		0.000	0.016	0.013	0.092	0.049	0.000	0.210	0.234
DTR (m)	Coef. corr.	0.688 **	1.000	0.740 **	0.706 **	0.520 **	0.418 *	0.517 **	0.456 **	0.220
	Sig. (bil.)	0.000		0.000	0.000	0.004	0.033	0.003	0.010	0.234
DTRAI 20-25km/h (m)	Coef. corr.	0.428 *	0.740 **	1.000	0.963 **	0.753 **	0.680 **	0.283	0.475 **	0.294
	Sig. (bil.)	0.016	0.000		0.000	0.000	0.000	0.123	0.007	0.109
Esf. 20 and 25 km/h (No.)	Coef. corr.	0.450 *	0.706 **	0.963 **	1.000	0.838 **	0.809 **	0.369 *	0.455 *	0.262
	Sig. (bil.)	0.013	0.000	0.000		0.000	0.000	0.045	0.012	0.161
DR (+25km/h) (m)	Coef. corr.	0.319	0.520 **	0.753 **	0.838 **	1.000	0.983 **	0.139	0.206	0.293
	Sig. (bil.)	0.092	0.004	0.000	0.000		0.000	0.471	0.284	0.123
Sprints (No.)	Coef. corr.	0.390 *	0.418 *	0.680 **	0.809 **	0.983 **	1.000	0.173	0.285	0.289
	Sig. (bil.)	0.049	0.033	0.000	0.000	0.000		0.398	0.158	0.152
Acc. (No.)	Coef. corr.	0.627 **	0.517 **	0.283	0.369 *	0.139	0.173	1.000	0.249	0.242
	Sig. (bil.)	0.000	0.003	0.123	0.045	0.471	0.398		0.177	0.189
Dcc. (No.)	Coef. corr.	0.231	0.456 **	0.475 **	0.455 *	0.206	0.285	0.249	1.000	-0.007
	Sig. (bil.)	0.210	0.010	0.007	0.012	0.284	0.158	0.177		0.969
Hamstring injury	Coef. corr.	0.220	0.220	0.294	0.262	0.293	0.289	0.242	-0.007	1.000
	Sig. (bil.)	0.234	0.234	0.109	0.161	0.123	0.152	0.189	0.969	

**The correlation is significant at the 0.01 level (two-sided). *The correlation is significant at the 0.05 level (two-sided).
(D) Duration (min), (DTR) Total distance traveled (m), (DTRAI) Total distance traveled at high intensity 20-25 km/h (m), (E) Efforts between 20-25 km/h, (DTR) Total distance traveled at more than 25 km/h (m), (Sprints) 30 m between 6-7 m/s^2, (Acc.) Number of accelerations (>1 m/s^2), (Dcc.) Number of decelerations (<−1 m/s^2)

Table 5. Stepwise model of the regressor variables

Variables	Punctuation	gl	Next.
D (min)	0.010	1	0.919
DTR (m)	0.149	1	0.699
DTRAI (20-25 km/h) (m)	0.209	1	0.647
Esf. 20 and 25 km/h (No.)	0.062	1	0.804
Sprints (No.)	0.222	1	0.637
Acc. (No.)	0.085	1	0.771
Dcc. (No.)	0.577	1	0.447
Global statistics	4.725	7	0.694

(D) Duration (min), (DTR) Total distance traveled (m), (DTRAI) Total distance traveled at high intensity 20-25 km/h (m), (E) Efforts between 20-25 km/h, (Sprints) 30 m between 6-7 m/s^2, (Acc.) Number of accelerations (>1 m/s^2), (Dcc.) Number of decelerations (<−1 m/s^2)

Table 6. Omnibus tests of model coefficients

	Steps	Chi squared	gl	Q
	Step	3.5	1	0.061
Step 1	Block	3.5	1	0.061
	Model	3.5	1	0.061

conducted by Hägglund et al. (2013) found that teams with high injury rates did not perform well compared to those with low rates in major competitions in Europe. Although sprinting did not present an association with hamstring injury in the study, Lahti et al. (2020) propose sprinting as a potential risk factor for hamstring injuries, expressing an interest in analyzing the mechanical acceleration results of said action. For Morin & Samozino (2016) the results in the mechanical acceleration outputs in the sprint are important in training orientation. In this regard, Edouard et al. (2021) concluded that optimizing horizontal force production capacity during sprinting can improve sprint performance and reduce the risk of injury. In this sense Mendiguchia et al. (2021), relating sprint kinematics to hamstring injury and performance, examined whether a specific 6-week multimodal intervention (combination of lumbopelvic control exercises and running technique) could lead to changes in pelvic kinematics and the lower extremities in actions at maximum speed and improvement in sprint performance. These authors concluded that such a training program induced clear kinematic changes in the pelvis and lower extremities during maximum speed running, associating these changes collectively with a reduced risk of muscle strain and with a significant improvement in sprint performance.

Regarding accelerations and decelerations, Akenhead et al. (2013) indicate that the number of decelerations in a match is greater than the accelerations; similar results were presented in the present study in which these variables were

analyzed. Important data when programming and directing the training process towards these actions, since in the face of continuous repetitions there could be fatigue at certain moments of the competition and training. For Lago (2014), this fatigue can occur due to maximum intensity efforts, acceleration and deceleration actions with and without the ball. For their part, Dalen et al. (2016) in addition to technical-tactical actions anticipating, running, jumping, intercepting, turning, changing direction, important efforts in the dynamics of current soccer and in the development of the competition that led to obtaining better results at the end of the matches. Given this trend, for Alonso (2018), an optimal organization and continuity of appropriate and specific stimuli in the soccer player's training process may allow them to cope with higher demands in the future.

For the analysis of the different external load indicators in competition during the season, contextual variables such as the state of the scoreboard, the level of the opponent and the location of the match were not taken into account. For Lucas (2020) these variables are important when analyzing a player individually or the team collectively during a season. The low incidence of non-contact hamstring injury reported in the study may indicate that training loads are being appropriately planned, monitored, and prescribed. Gabbett (2016) links high training loads and injuries, demonstrating that the problem is not in the training itself, but probably in inappropriately applied stimuli. Excessive and rapid increases in training loads are probably largely responsible for this type of injury.

Monitoring external load in training and matches is essential in the design and planning of adequate training to achieve optimal physical preparation for competition and reduce the risk of injury (Malone et al., 2017; Owen et al., 2015).

Conclusions

The logistic regression model ($p>0.05$) did not present statistical significance, consequently, none of the monitored external load regressor variables explains the rate of hamstring injuries in this population, therefore, based on the results found, it is not possible to reject the null hypothesis of the study.

During the 2021-1 season, there were 2 non-contact hamstring injuries, which can be established as a low number of injuries for professional soccer players of the Club under investigation. Therefore, it can be considered that the findings regarding the training and competition load developed by the athletes were adequate in terms of the low number of hamstring injuries that occurred, possibly this aspect has decreased the risk of injuries of those soccer players, during that specific period of time.

It is noteworthy that the results obtained in the present study correspond to professional soccer players from a specific club during the 2021-1 season, therefore, the findings cannot be generalized since they were presented in a specific population, season and competition under conditions individuals (during the pandemic generated by COVID-19).

Limitations

It is important to recognize and declare that the study was developed during critical episodes of the pandemic generated by COVID-19, which generated difficulties and modifications due to mobility, training and competition restrictions. Likewise, the study was carried out during the 2021-1 season, making it a short period of time for the analysis of the variables of interest. The results of this study are only inferable to the players of the professional team investigated.

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З'ясування взаємозв'язку між зовнішнім навантаженням і частотою травм підколінного сухожилля у професійних футболістів

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 6 табл., 33 джерела.

Мета. Метою дослідження було проаналізувати показники зовнішнього навантаження з частотою виникнення неконтактних травм підколінного сухожилля.

Матеріал та методи. Було проведено неекспериментальне кореляційне, ретроспективне когортне дослідження. Дані були зібрані у 31 професійного футболіста чоловічої статі протягом одного сезону. Досліджено наступні показники навантаження: тривалість (D), загальна пройдена відстань (TDT), відстань, пройдена з високою інтенсивністю (DTHI) > 20 км/год, кількість зусиль між 20-25 км/год (NE 20-25 км/год), відстань, пройдена зі швидкістю понад 25 км/год (DR+25 км/год), кількість спринтерських забігів понад 25 км/год (NE > 25 км/год), кількість прискорень понад 1 м/с^2 (Acc) та кількість незначних сповільнень до -1 м/с^2 (Dcc). До аналізу були включені лише неконтактні ушкодження підколінного сухожилля. Для багатовимірного аналізу було застосовано логістичну регресійну модель, де було встановлено значення $p < 0,05$ як для статистичної значущості моделі (X^2), так і для кожної зі змінних регресорів (X^2), рівень довірчого інтервалу становив 95%.

Результати. Зафіксовано та діагностовано наявність двох травм: ушкодження другого ступеня та м'язова втома. Проаналізовані показники навантаження не показали достовірної кореляції з ушкодженням підколінного сухожилля. Таким чином, зв'язку між зовнішнім навантаженням і травмою підколінного сухожилля у професійних футболістів не встановлено.

Висновки. Логістична регресійна модель ($p > 0,05$) не продемонструвала статистичної значущості. Отже, жодна з досліджуваних змінних зовнішнього навантаження не пояснює частоту неконтактних травм підколінного сухожилля в цій категорії досліджуваних.

Ключові слова: індикатори зовнішнього навантаження, травма підколінного сухожилля, система глобального позиціонування (GPS).

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Enhancing Anaerobic Endurance in Student Futsal Players through Small-Sided Games Combined with High-Intensity Interval Training

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Abstract

Objectives. Futsal is a team sport that requires anaerobic support tactics and playing techniques, some of which include attack versus defend and high-intensity interval training (HIIT). The aim of this study was to determine the effect of training small-sided games with high-intensity interval training on the anaerobic endurance of futsal players.

Materials and methods. In this study, a one-group pretest-posttest design was used. The study population consisted of 25 players. 16 players were selected with an average age of 15.9 ± 0.5 years, height 158.1 ± 5.79 cm, weight 58.9 ± 9.79 kg, and BMI 19.9 ± 2.41. The research data were analyzed using the paired sample t-test.

Results. Based on the results of the paired sample t-test, it was found that the sig (2-tailed) values were 0.002 < 0.005, indicating a significant increase in anaerobic endurance.

Conclusions. It can be concluded that small-sided game training with high-intensity interval training contributes significantly to the improvement of anaerobic endurance in student futsal players.

Keywords: futsal, small-sided games, high-intensity interval training, anaerobic endurance.

Introduction

Futsal is an intermittent sport that requires high physical, technical, and tactical demands. Players engage in high-intensity locomotor activity and require both aerobic and anaerobic endurance (Barbero-Alvarez et al., 2008; Mendes et al., 2022; Ribeiro et al., 2020). Tactical ability is a crucial element for success in futsal. Futsal is a team sport that requires high intensity and involves physical abilities, techniques, and tactics. The game is characterized by short recovery periods (Da Cruz et al., 2020; Naser et al., 2017; Ohmuro et al., 2020). The game is also known for its high-intensity efforts and frequent sprinting activities, which necessitate players to perform at a high level of physical ability (Caetano et al., 2015). Futsal, like football, demands a comprehensive comprehension of tactical aspects such as attack, defense, and transition. This sport falls under the category of competitive sports, and players are able to maintain a specific formation during the game (Narizuka & Yamazaki, 2019). They must also be capable of fulfilling various roles, such as organizing attacks and guarding the defense, as part of a team. Proficiency in these tactics not only affects the outcome of the match but also reflects the caliber of the players and the team as a whole.

To play with high intensity and execute planned tactics, players must possess high anaerobic abilities, which require a high level of fitness. Supporting the application of tactics, techniques, and physicality in the game is crucial (Milioni et al., 2016). Anaerobic endurance refers to the body's ability to produce energy quickly and powerfully. Futsal sports demand high levels of anaerobic energy (Farhani et al., 2019). In intense matches like futsal, players must possess the physical strength to maintain high performance, pressure opponents, and actively participate in attacking and defensive patterns.

This research focuses on training that combines game tactics elements, including attack versus defense, with

HIIT to meet these needs. The exercise uses the anaerobic energy system to improve physical abilities related to anaerobic energy, such as endurance and speed (Ouertatani et al., 2022). High-Intensity Interval Training (HIIT) is commonly utilized in soccer games due to the similarities in match intensity between soccer and futsal (Barnes et al., 2014; Hostrup & Bangsbo, 2023; Rodrigues et al., 2011). Previous research has explored the effects of HIIT on agility and dribbling skills in futsal (Wiranata et al., 2023), but its impact on the anaerobic endurance of futsal players can also enhance their tactics and on-field performance.

The importance of understanding how integrated high-intensity tactical and physical training can impact student soccer players makes this research urgent. The results of this study can provide valuable guidance for coaches and players to design more effective and targeted training programs to significantly improve futsal players' anaerobic endurance.

Materials and Methods

Study Participants

The total population used in this research was 25 players who participated in extracurricular activities. The sample used in this research was 16 randomly selected players. The characteristics of the sample used were 15.9 ± 0.5 years old, with a height of 158.1 ± 5.79 cm, a body mass of 58.9 ± 9.79 kg, and a BMI of 19.9 ± 2.41.

Study Organization

This study employed a one-group pre-test and post-test design. The research was conducted over a period of six weeks, with three sessions per week (Ziemann et al., 2011). Prior to treatment, subjects underwent a pre-test to establish baseline data on anaerobic capacity. A post-test was then administered after six weeks of treatment. The average difference for each subject was determined by analyzing the difference between the pre-test and post-test data. The research employed the Running-based Anaerobic Sprint Test (RAST) to train anaerobic endurance (Andrade et al., 2015). The RAST test requires participants to sprint as fast as possible over a certain distance, typically around 35 meters, with short rests between each sprint. The test consists of 6 sprints. The variables to be analyzed in RAST are peak power (W), minimum power (W), total effort time (s), and fatigue index (FI) (calculated as (peak power – minimum power)/peak power) × 100).

Training Program

This study involved 16 subjects divided into four groups, each consisting of four individuals. One group comprised two attacking players and two defensive players. The first group played Small Sided Games (SSG) 2 against 2 without a goalkeeper for 90 seconds in an area measuring 20×20 meters, with the target intensity reaching 80-90% of the maximum heart rate (HR max). Two small goal targets were placed at each end of the pitch to add a competitive element. Meanwhile, the other three groups waited in pairs outside the area while the training interval, consisting of 90 seconds of HIIT and 270 seconds of active recovery, was carried out. After completing the first repetition, each group alternated with the second group to continue the same exercise at 80-90% intensity for 90 seconds. This process continued until each group had completed 8 repetitions.

Statistical Analysis

The research utilized data analysis methods such as the Shapiro-Wilk normality test and the Paired Sample T-test to compare pre-test and post-test results. The significance level (Sig) was found to be less than 0.05.

Results

The results of the descriptive statistical analysis of the pre-test and post-test RAST of student futsal players are presented in the table below.

Table 1. Descriptive Statistics

Variable	Pretest	Posttest
Peak Power (w)	481.75±89.61	551.75±132.27
Minimum Power (w)	299.89±47.11	287.58±44.31
Total Effort Time (s)	34.23±1.20	33.93±1.53
Fatique Index (FI)	5.35±1.85	7.92±3.50

The data are presented by means ± SD

Table 1 presents the results of the descriptive statistical analysis, indicating an increase in scores from pre-test to post-test. In the pre-test, scores had a mean value of 5.35±1.85. In contrast, the average score in the post-test increased to 7.92±3.50. These findings suggest that the intervention led to improved performance among participants.

Table 2. Normality Test Results

Variable		Shapiro-Wilk		
		Statistics	N	Sig
Fatique Index	Pretest	0.909	16	0.112
	Post-test	0.903	16	0.089

The data is presented as means ± SD and statistical significance. To determine normality, the Shapiro-Wilk test was used, with data considered normal if the significance level was ≥0.05

Based on the results presented in Table 2, the normality test using the Shapiro-Wilk test instrument showed that the pre-test fatigue index value was 0.112, which is greater than the significance level of 0.05. Similarly, the post-test fatigue index value was 0.089, which is also greater than the significance level of 0.05. Therefore, all research data was normally distributed, and parametric statistics paired sample t-test was used for hypothesis testing. The data are presented as ± SD and significance values. According to the Shapiro-Wilk test, data is considered normal if the significance value is greater than 0.05.

According to the results presented in Table 3, the fatigue index data obtained from the hypothesis testing using the Paired Sample T-Test indicates a sig (2-tailed) value of

Table 3. Hypothesis Test Results

Paired Difference					T	df	Significance
Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				Sig. (2- tailed)
			Lower	Upper			
-2,71	2,82	0,70	-4,22	-1,20	-3,84	15	0,002

The data is presented as means ± SD. Any statistically significant differences are denoted by a sig (2-tailed) value of ≤ 0.05 when comparing mean scores to the baseline

0.002<0.05. Therefore, it can be concluded that there is a significant increase in anaerobic endurance through SSG with HIIT.

Discussion

The aim of this study was to investigate the effects of SSG with HIIT on the anaerobic endurance of student futsal teams. The training was conducted for 1 month and 2 weeks, with a frequency of 3 meetings per week, while adhering to the principles of training and increasing the load every week. This study is consistent with previous research, which also administered treatment 3 times a week (Kumar & Pandey, 2023; Mashud et al., 2019; Yan et al., 2022). The research results indicate that SSG with HIIT has a positive effect on anaerobic endurance, as demonstrated by a decrease in the player's fatigue index.

Anaerobic endurance is increased through high-intensity exercise alternated with short rest periods. When high-intensity exercise is performed in the anaerobic zone for an average of 90 seconds, lactic acid is produced. In theory, if training is always conducted in the lactic anaerobic zone and is interspersed with short breaks, it will improve the lactic acid tolerance of the muscles. This will result in the muscles not tiring easily during these exercises. Previous research supports this idea, as high-intensity training has been shown to positively affect anaerobic ability (Bravo et al., 2008; McGinley & Bishop, 2016; Stöggl & Björklund, 2017). High-intensity exercise interspersed with short rest periods is an effective training method for improving athletes› metabolic and cardiovascular function (Buchheit & Laursen, 2013; Foster et al., 2015; Kunz et al., 2019). This type of exercise is known as intermittent exercise, which involves alternating short periods of high-intensity activity with low-activity recovery or rest phases (Cavar et al., 2019; Norton et al., 2010; Sloth et al., 2013).

The training model used in the research features a game in which players face an equal number of situations and aim to score quickly. This model is based on the demands of a match, requiring each player to perform a series of intense activities, such as sprinting, changing direction, and accelerating during training. This approach aligns with the findings of (Spyrou et al., 2020). Increasing anaerobic ability can have a positive impact on actions during small-sided games, such as passing and shooting. This is supported by research conducted by Apriantono et al. (2021), who found a strong correlation between anaerobic ability and explosive movements like passing, tackling, heading, and shooting. On the other hand, this training model has the advantage of being suitable for the high-intensity demands of the game. Additionally, each group has the opportunity to participate in 2 versus 2 small-sided games without a goalkeeper, which provides high intensity training while allowing for sufficient rest time through active recovery. Paired passing drills outside the area enable the resting group to stay involved in the drill and maintain their body temperatures. This exercise is an alternative high-intensity activity that can be performed at or near maximum capacity. The training model includes a holistic approach that incorporates elements of technique and tactics into physical training. This approach is based on the recommendations of Kusuma et al. (2024), who concluded that a holistic approach is ideal for training. According to (Engel et al., 2018) improving endurance and anaerobic performance variables can save time for adolescent athletes. However, this research has yet to test the effect of training in terms of tactics or techniques. Therefore, further research is needed to determine the effectiveness of this training in those areas.

Conclusions

According to the research and discussion results, the use of SSG with HIIT methods has a significant impact on the anaerobic endurance of student futsal players. This is characterized by a decrease in fatigue levels.

Conflict of interest

The authors guarantee that no conflicts of interest exist.

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Підвищення анаеробної витривалості у студентів-футзалістів шляхом поєднання ігор з обмеженою кількістю гравців та високоінтенсивним інтервальним тренуванням

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 5 с., 3 табл., 33 джерела.

Мета дослідження. Футзал є командним видом спорту, який потребує застосування анаеробних тактичних прийомів та ігрових технік, деякі з них включають комбінації нападу проти захисту та високоінтенсивні інтервальні тренування (ВІІТ). Метою цього дослідження було визначити вплив застосування тренувальних ігор з невеликою кількістю гравців та високоінтенсивного інтервального тренування на показники анаеробної витривалості футзалістів.

Матеріали та методи. У цьому дослідженні застосовано метод претесту та посттесту для однієї групи. Категорія досліджуваних складалася з 25 гравців. Було відібрано 16 гравців із середнім віком 15,9 ± 0,5 років, зростом 158,1 ± 5,79 см, масою тіла 58,9 ± 9,79 кг та ІМТ 19,9 ± 2,41. Дані дослідження було проаналізовано із застосуванням t-критерію для парних вибірок.

Результати. На підставі результатів t-критерію для парних вибірок було встановлено, що sig (2-tailed) (значимість (2-стороння)) становила 0,002 < 0,005, що свідчить про суттєве збільшення показників анаеробної витривалості.

Висновки. Таким чином, можна зробити висновок, що ігрові тренування з обмеженою кількістю гравців у поєднанні з високоінтенсивним інтервальним тренуванням істотно сприяють покращенню анаеробної витривалості у студентів-футзалістів.

Ключові слова: футзал, ігри з обмеженою кількістю гравців, високоінтенсивне інтервальне тренування, анаеробна витривалість.

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The Effects of Football Training on Improving Aerobic Skills, Technique, and Anthropometry in Goalkeepers

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Abstract

Objectives. The study aimed to assess the impact of football training, particularly for goalkeepers, on children's motor skills and aerobic capacity over a 10-month period.

Materials and methods. This experimental study focused on evaluating the specific skills of goalkeepers and the aerobic capacities of children who took on the role of goalkeeper after undergoing training. The study involved totally 20 individuals aged 10-14 who played as goalkeepers and who were part of the entire population trained at the Real Madrid Foundation UNY Football School. The changes in the goalkeeper's aerobic capacity, reaction speed, and diving, as well as anthropometric measurements were found in the study. The instruments used for this research included a multi-stage fitness test, a test of the goalkeeper's reaction and diving skills, as well as height and weight measurements. The data analysis technique used was the t-test to determine differences in variables between the pretest and post-test, with a significance level of less than 0.05 ($p < 0.05$).

Results. The results revealed significant improvements in aerobic endurance ($p = 0.004$), reaction ability ($p = 0.007$), and goalkeeper diving ($p = 0.002$) after 10 months of football training. However, there were no significant changes in height, weight, and BMI, as the p value was greater than 0.05.

Conclusions. These findings have important implications for evaluating goalkeeper training programs and provide a basis for recommending more effective ones.

Keywords: goalkeepers, aerobics, reaction speed, anthropometry.

Introduction

The goalkeeper plays a crucial role in a football match, being one of the last players defending the team's goal from opponent attacks. Apart from preventing the ball from entering the goal, the goalkeeper also leads and organizes the team's defense and coordinates with other players on the field (Katanić et al., 2021). Over the years, goalkeeping has gained immense respect in the world of football, as demonstrated by the many famous goalkeepers who have achieved awards and set records in their careers. After Euro 1992, several football match rules changed, including the prohibition of back passes to the goalkeeper, emphasizing the need for modern goalkeepers to have exceptional ball control skills. During a match, goalkeepers perform various techniques, such as making saves (41.6%), stopping the ball with their feet (27.8%), parrying the ball (12.6%), and executing flying movements (10.3%) (Rebelo-Gonçalves et al., 2017). Despite this, the goalkeeper position is often overlooked in sports science research, and a multidisciplinary scientific approach is required to understand the talent scouting process (Knoop et al., 2013). The physical and technical abilities of young goalkeepers must be carefully considered when identifying special talents, as highlighted in the 2014 FIFA reports and statistics in Brazil, emphasizing the importance of the training process for junior and senior goalkeepers (Muracki, 2020).

While all players have the potential to act as a goalkeeper during a match, specific conditions are required (FIFA, 2022). The abilities of a goalkeeper differ significantly from those of other players on the team, as they also play a crucial

role in organizing both slow attacks from behind and fast counterattacks (Parada & Vargas, 2020). The ability to concentrate, perceive the target of the kick and anticipate a player's kicking style are essential for a goalkeeper to effectively defend the goal (Wood & Wilson, 2010). Goalkeepers must possess the skills to read and react to these dynamic situations, requiring a high level of alertness during a game (Jarraya et al., 2014). A goalkeeper's decision-making abilities are central to their training (F. W. Otte et al., 2020), and aside from strong physical and technical attributes, mental capabilities are also crucial. These mental abilities include understanding how to approach penalty kicks, controlling the tempo to disrupt the opponent's concentration, and generating momentum for the team (Furley et al., 2017).

Aerobic endurance is a fundamental requirement for every sport, including football, especially considering the long durations and expansive fields involved (Hardinata et al., 2021). International soccer players typically exhibit aerobic endurance levels ranging from 50 to 75 ml kg/min, highlighting its significant contribution to players' overall quality (Jemni et al., 2018). The continuous 90 minutes of football gameplay heavily relies on the aerobic energy system (Dzimbova & Ivanov, 2023), emphasizing the critical nature of maintaining aerobic endurance throughout the season (Kalinowski et al., 2021). Aerobic exercise plays a vital role in enhancing heart function in young children (Suarez-Tijeras et al., 2023), and conflicting data exists in early childhood regarding approaches to aerobic endurance training, as highlighted in research by Charalampos et al. (2013). Without adequate aerobic endurance, soccer players may struggle to sustain their performance for the full 90 minutes of a match, underscoring the pivotal role of aerobic endurance in determining overall performance (Gonçalves, Clemente, Barrera, Sarmento, González-Fernández, Rico-González, et al., 2021)

Anthropometry involves the study of the size and proportions of the human body and their correlation with physical performance. Within sports, anthropometry is commonly utilized to identify factors that can impact an athlete's overall performance. In the context of football, anthropometry holds particular significance for the goalkeeper position, which demands physical strength and effective body coordination. Studies focusing on the anthropometry of goalkeepers have revealed that factors such as height and arm-to-body ratio can significantly influence their ability to defend the goal. Furthermore, human body proportions play a pivotal role in shaping team performance and the specific positions played (Karakaş et al., 2011). An understanding of anthropometry holds the potential to markedly influence performance in the field. The growing body of research in the field of anthropometry is indicative of the increasing emphasis placed on this area of study (Kaplánová et al., 2020).

Materials and Methods

Study Participants

This research employed an experimental one-group pretest and post-test design to assess the development of technical abilities, aerobic endurance, and anthropometric changes following 10 months of football training, with a specific focus on goalkeepers. The study involved 20 goalkeepers aged 10-14 who underwent training at the Real Madrid Foundation Football School, Yogyakarta State University (UNY). All participating students received detailed information and provided written consent, signed by both the students and their guardians, consenting to their inclusion as research subjects.

Measurement

Before commencing a series of training programs, the data was gathered regarding the children's physical abilities, technique, height, and weight. The conducted tests encompassed the following: 1) anthropometric measurements, wherein body weight and height were assessed utilizing scales and a stadiometer, 2) measurements of aerobic endurance, which were conducted via a multistage test, 3) measurements of reaction ability to block the ball and diving, which were assessed through evaluations of reaction speed and goalkeeper diving.

Training protocol

Every child undergoes a warm-up session comprising a 3-minute static warm-up followed by a 7-minute dynamic warm-up, featuring movements derived from FIFA's Eleven Plus Movements and sports stretch book texts. Subsequently, each child engages in a 50-minute core training session, encompassing two main parts: 30 minutes of integrated technical training focused on goalkeeper physical skills and 20 minutes of game situation exercises. The goalkeeper training regimen occurs three times a week over a period of 10 months. Additionally, comprehensive class sessions are conducted every two months, providing in-depth explanations of goalkeeping techniques.

Table 1. Duration of each training session

No	Training Composition	Duration
1	Warming-up	10 minutes
2	Core Training:	
3	Physical Integration Technique Training	30 minutes
4	Game	20 minutes
5	Cooling down	5 minutes

Statistical Analysis

The data analysis technique employed in this research includes several key components: 1) Description test involving providing a descriptive summary of the data, 2) normality test, the Shapiro-Wilk test to assess whether the data exhibits a normal distribution; 3) homogeneity test, the Levene's Test with the F test to evaluate the homogeneity of variance, specifically to determine the similarity of variances in the pretest and posttest experimental group data. This test aims to establish if the data distribution (variance) of the two experimental groups is not heterogeneous, ensuring they possess balanced traits or characteristics suitable for comparison (van Breukelen & Candel, 2021). The data distribution (variance) of the two experimental groups is declared

homogeneous if the Levene test results show a significance value of p>0.05; 4) t-test to ascertain differences in variables between the pretest and posttest in the experimental group. A significance value of less than 0.05 ($p < 0.05$) indicates a notable difference. The data from the initial test (pretest) and final test (posttest) are statistically analyzed using the t test within the SPSS version 27 program, with a significance level of 5% or 0.05; 5) Cohen's d test to assess the effect size before and after the intervention. The effect sizes are classified as small (0.2), medium (0.5), and large (0.8) based on the categorization by Hopkins et al. (2009). This comprehensive analytical approach provides a robust basis for evaluating the impact of the intervention.

Results

The Results of the Pre-Test's Descriptive Statistic

Based on measurements of aerobic ability, technique, and anthropometry conducted prior to the training/intervention, descriptive statistical results are presented in Table 2.

Table 2. The results of the pre-test's descriptive statistic (n = 20)

Indicators	Mean	SD	Minimum	Maximum
Height, m	1.52	0.123	1.31	1.71
Weight, kg	49.75	13.42	29.50	71.60
BMI, kg/m^2	21.15	4.55	13.37	29.11
VO_2max, ml/kg/min	30.98	6.00	22.20	43.70
Reaction	4.10	1.37	2.00	7.00
Diving	4.70	1.38	2.00	7.00

The Results of the Post-Test's Descriptive Statistic

The following table shows the results of the descriptive statistics after the intervention was given in this study. It can be seen in Table 3 as follows.

Table 3. The results of the post-test's descriptive statistic (n = 20)

Variables	Mean	SD	Minimum	Maximum
Height, m	1.53	0.121	1.32	1.71
Weight, kg	50.01	13.12	29.50	71.60
BMI, kg/m^2	21.20	4.45	13.20	29.11
VO_2max, ml/kg/min	35.75	6.19	24.30	45.30
Reaction	5.45	1.50	3.00	8.00
Diving	6.30	1.71	3.00	9.00

After conducting descriptive statistical tests, it is evident that there has been an increase in all variables. However, further analysis is required to ascertain the significance of these results. The mean value is depicted in the following picture.

The Results of the Normality Test

The normality test using the Shapiro-Wilk test explains that all data are normally distributed because all results obtained a significant value > 0.05. These results can be seen in Table 4.

Table 4. The results of the data normality test

Indicators	Pre-test		Post-test	
	s-w	p	s-w	p
Height	0.946	0.310	0.944	0.279
Weight	0.945	0.301	0.953	0.420
BMI	0.957	0.479	0.961	0.572
VO_2max	0.963	0.605	0.961	0.567
Reaction	0.939	0.233	0.945	0.293
Diving	0.950	0.372	0.953	0.421

The Results of the Homogeneity Test

The homogeneity test uses the Levene Statistic. In Table 5, it is explained that all data are homogeneously distributed because all results obtained a significant value > 0.05.

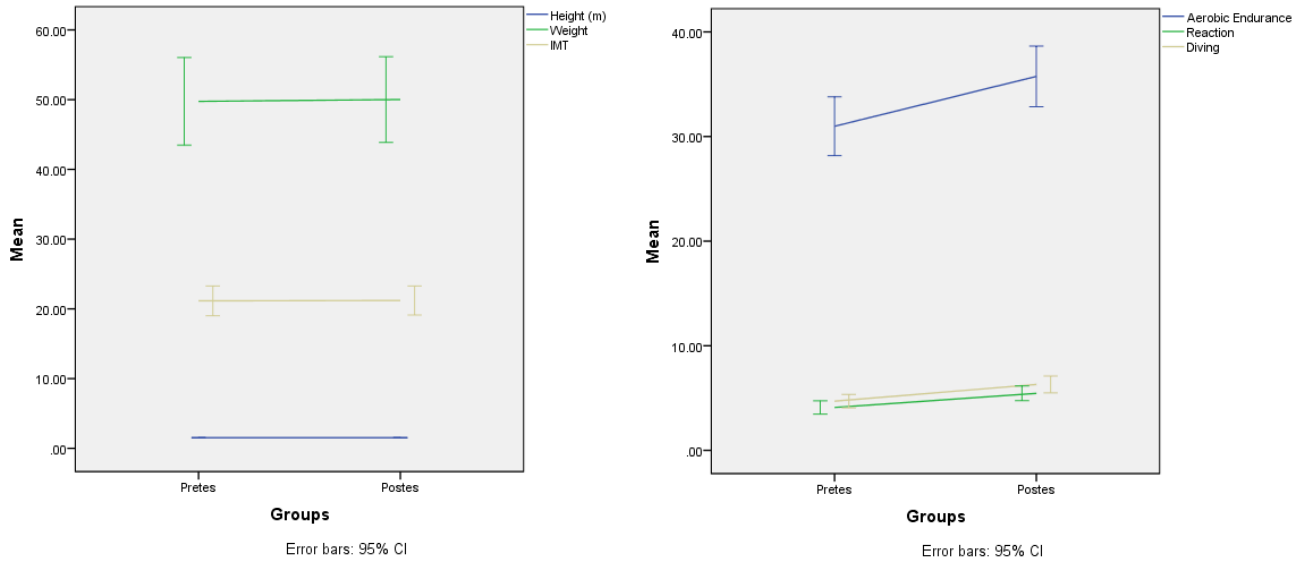

Fig. 1. The mean value is depicted

Table 5. The results of the homogeneity test

Indicators	Levene Statistic	p
Height	0.005	0.945
Weight	0.018	0.893
BMI	0.020	0.889
VO_2max	0.106	0.747
Reaction	0.700	0.408
Diving	1.317	0.258

Hypothesis Testing

Once the data has passed the prerequisite test, indicating that all data is normally distributed and homogeneous, hypothesis testing is conducted. The following presents the results of the Paired Sample T-test to address the hypothesis in this research.

Table 6. The results of the hypothesis testing

Variables	Indicators	EG			
		Mean	t count	p value	ES
Anthropometry	Height	0.003	1.831	0.083	0.41
	Weight	0.260	0.806	0.430	0.18
	BMI	0.049	0.396	0.696	0.09
Aerobic Endurance	VO_2max	4.770	3.275	0.004	0.73
	Reaction	1.350	3.048	0.007	0.68
Technique	Diving	1.600	3.606	0.002	0.81

Based on the above Table 6, this research found no significant changes in the goalkeeper's weight and height. However, the goalkeeper experienced significant changes in aerobic endurance ($p = 0.004$), reaction technique ability ($p = 0.007$), and diving technique ability ($p = 0.002$) as their P-values were less than 0.05. Upon examining the Effect Size (ES), it is observed that the anthropometric variable shows small changes (small effect), whereas the aerobic endurance and technique variables exhibit large changes (large effect).

Discussion

The study results did not indicate a significant difference between height before and after exercise; however, the average height of children did increase. Typically, height increases by 5 cm per year during the growth period. Growth starts at 0.2 m at birth and reaches 1.73 m in adolescence (Alvear-Vasquez et al., 2023). The growth of children's height is influenced by the hormones estrogen and testosterone, which stimulate bone and body tissue growth. Testosterone plays a significant role in growth for boys. Moreover, genetic factors also contribute to a child's height growth, as the height of both parents can influence the child's height.

Aligned with the research conducted by Mohr et al. (2015), physical activities such as football, swimming, and brisk walking were found to influence bone density, consequently impacting a child's height. Similarly, the study by Larsen et al. (2017) indicated that long-term physical activity led to high levels of bone mineral content and bone mineral density in the lower limbs of football players.

In general, children between the ages of 10 and 15 will undergo natural height changes as part of their physical development. The final height is influenced by genetic, nutritional, hormonal, and environmental factors. Parents and coaches can offer support and education to facilitate optimal growth. A balanced diet, including sufficient protein, calcium, vitamin D, vitamin C, and iron, plays a crucial role in a child's height. It is important to avoid fast food to prevent obesity. Regular exercise promotes the optimal functioning of growth hormones, while adequate rest also contributes to children's growth.

Anthropometry can significantly impact a goalkeeper's performance in a football match, particularly height. While height is not the sole determining factor for a team's success, it plays a crucial role. Each position on the field possesses distinct characteristics. A goalkeeper's height greatly aids in defending the goal, while tall defenders are adept at thwarting overhead ball attacks and are challenging to bypass. Conversely, height is not a primary consideration for players in other positions. Notably, the French national team, runners-up in the Qatar 2022 World Cup, had an average height of 185.4 cm. It is essential to consider factors that can support the optimal growth of young children and teenagers.

In this study, no significant difference in body weight was observed before and after 10 months of training, with the average body weight ranging from 49.75 kg to 50.01 kg. The most significant weight changes in children typically occur during infancy, while from ages 4 to 10 years, the ideal weight change is 2 to 3 kg per year. From ages 11 to 18 years, this changes to 3 to 5 kg per year. Maintaining an ideal body weight facilitates football players in enhancing speed, agility, and endurance, while also reducing the likelihood of easily sustaining injuries, as opposed to overweight players who are more susceptible to muscle and ligament injuries.

The body weight is influenced by food, exercise, and lifestyle changes, with the food consumed being adjusted to match the expended energy needs. Children need to avoid unhealthy lifestyles, such as staying up late and smoking, to maintain a healthy weight. Regular exercise has a significant impact on children's overweight levels. According to Muracki et al. (2021), goalkeepers sometimes have a higher fat percentage than players in other positions. Maintaining body weight is crucial for agility in movement, speed, and the body's reaction to the arrival of the opponent and the ball. The goalkeeper position requires the player to cover the shortest distance compared to other positions on the field.

Conducting football training over a 10-month period, with three sessions per week, can significantly enhance aerobic endurance, a crucial requirement for the sport. Numerous studies have explored the impact of regular and intensive football training on aerobic endurance. Naser et al. (2017) conducted research indicating that just eight weeks of football training can enhance an individual's aerobic endurance. Similarly, Krustrup et al. (2010) found that 12 weeks of football training can notably increase an individual's maximum oxygen capacity (VO_2max), a key measure of aerobic endurance. VO_2max reflects the body's ability to effectively utilize oxygen during physical activity. Furthermore, Dzimbova and Ivanov (2023) have affirmed

that exercise plays a significant role in improving aerobic endurance.

The enhancement of aerobic endurance is influenced by factors such as age, exercise intensity, and duration. Football has been shown to boost lung capacity, enabling increased oxygen intake. Both aerobic and anaerobic endurance play pivotal roles in maintaining physical fitness during football matches and are crucial determinants of victory (Gonçalves, Clemente, Barrera, Sarmento, González-Fernández, Vieira, et al., 2021). Additionally, these types of endurance contribute to the efficient functioning of the heart in circulating blood throughout the body. Aerobic endurance is particularly vital for football players, as they must sustain their performance over 90 minutes, covering 10-12 km with 70% oxygen intensity. Improving aerobic endurance enhances the heart and lungs' efficiency in supporting physical movements. Football training has been found to enhance endurance (Hoff et al., 2002), thereby improving a player's running distance, intensity, and ball involvement (Helgerud et al., 2001).

Goalkeepers rely heavily on various physical abilities to maintain concentration throughout the match (Lisenchuk et al., 2021). Research by F. W. Otte et al. (2020) emphasizes the need for goalkeepers to develop strength, endurance, speed, coordination, and agility. While goalkeepers may excel in jumping ability, their VO_2max might not be as high (Muracki et al., 2021). In football, goalkeepers require strong visual abilities, including spatial awareness, reaction comprehension, and coordination between eyes and limbs (Shafizadeh & Platt, 2012). The physical training of goalkeepers demands a prolonged period to cultivate specific automation and achieve optimal physical adaptation. The degree of physical fatigue and the speed of recovery are greatly influenced by the effectiveness of the training regimen. Hence, coaches must have a deep understanding of how to provide both physical and technical training tailored to the unique demands of goalkeeping (Jara et al., 2019).

The study's findings revealed a significant improvement in goalkeepers' reaction speed following 10 months of training. This aligns with research by Rozi et al. (2023), which emphasizes that agility training can enhance a goalkeeper's reaction speed, a factor influenced by reflexes. A goalkeeper's reaction speed is vital for thwarting opponents' goal attempts, making it essential for goalkeepers to consistently work on enhancing this attribute. The ability to react swiftly is crucial in determining a goalkeeper's proficiency, as it often determines whether they can successfully block the opponent's shots. To improve reaction speed, goalkeepers can engage in specific training exercises, such as practicing turns and stops, training with their back to the ball before swiftly turning to catch it, and working with bouncing balls (Singchainara et al., 2022). Additionally, the development of goalkeeping skills can be facilitated through various visual training methods (Rusu et al., 2011).

A goalkeeper's reaction speed becomes crucial during scenarios such as free kicks, corner kicks, or when the ball is headed towards the goal. Immediate response to a fast-moving ball is essential for the goalkeeper to effectively defend the goal. Engaging in specific warm-up routines, such as simulating match movements, can help goalkeepers enhance their reaction time (Obetko et al., 2020). When facing a penalty kick, goalkeepers must possess the ability to analyze and anticipate the opponent's kicking technique (Noël et al., 2021). Training for accuracy in predicting and intercepting kicks is a fundamental skill that goalkeepers must continually refine (Dicks et al., 2011)

The goalkeeper position holds significant importance within any football club (F. Otte, 2021). Key elements of goalkeeper techniques encompass the fundamental goalkeeper stance, positioning, as well as the skills to catch and save low and high balls, roll the ball to a teammate, execute kicks, punch the ball, and make throws. Milanović et al. (2012) observed that the most commonly utilized techniques by goalkeepers were saves (41.6%), foot controls (27.8%), clearances (12.6%), and aerial plays (10.3%).

The goalkeeper's role extends beyond defending the goal; they also play a pivotal part in the team's offensive strategies (Struzik, 2020). In addition to possessing exceptional technique, goalkeepers require intelligence, decision-making acumen, and robust physical capabilities. Their distinct ability to utilize their hands in the game contributes to their high and intricate level of uniqueness (F. W. Otte et al., 2020). Goalkeepers must adeptly balance basic football playing skills with the ability to prevent goals. Furthermore, they need specialized proficiency in thwarting penalty kicks (Navarro et al., 2013). The effectiveness of a goalkeeper can be gauged by their adeptness in making saves and securing victories for the team (Montesano, 2016). Understanding a goalkeeper's value necessitates knowledge of their reaction speed and physical condition data.

In formulating conclusions from this study, it is crucial to acknowledge several limitations that could impact result interpretation and the applicability of the findings. Firstly, the study's sample was confined to children aged 10-14 years of training at the Real Madrid Foundation UNY Football School, potentially limiting the extension of the findings to the broader football population. Furthermore, the 10-month training duration may not suffice to observe the long-term effects of football training on anthropometric variables. Other constraints encompass the utilization of measurement methods, such as multistage tests, which may not comprehensively represent overall aerobic capacity. Hence, further research involving larger sample sizes, prolonged training periods, and more sophisticated measurement techniques may be necessary to validate and broaden these findings. Despite these limitations, the study's results still offer a valuable contribution to comprehending the impacts of football training in children, while also indicating avenues for future research in this domain.

Conclusions

Based on the research findings, it is evident that football training spanning a 10-month period yielded noteworthy alterations in aerobic endurance ($p = 0.004$), reaction ability (0.007), and goalkeeper diving technique ($p = 0.002$). Conversely, no significant changes in height, weight, and BMI were observed, as evidenced by p values exceeding 0.05. These discoveries carry substantial implications for assessing goalkeeper training regimens and lay the groundwork for recommending more efficacious training programs. Moreover, these observations underscore the significance of accounting for children's growth phase within the 10–14-year age range, necessitating careful consideration of anthropometric aspects when devising optimal exercise programs.

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Conflict of interest

The authors guarantee that no conflicts of interest exist.

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Вплив футбольних тренувань на покращення показників аеробних навичок, техніки та антропометрії воротарів

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 6 табл., 44 джерела.

Мета дослідження. Дослідження мало на меті оцінити вплив футбольних тренувань, зокрема для воротарів, на розвиток рухових навичок та аеробних можливостей у дітей протягом 10-місячного періоду.

Матеріали та методи. Це експериментальне дослідження було сфокусовано на оцінці специфічних навичок воротарів та аеробних здібностей дітей, які взяли на себе функцію воротаря після проведення тренувань. Загалом у дослідженні взяли участь 20 осіб віком від 10 до 14 років, які грали на позиції воротаря і були частиною всієї групи, що тренувалася у футбольній школі UNY Фонду «Реал Мадрид». В ході дослідження було встановлено зміни в показниках аеробних можливостей воротаря, швидкості реакції та техніці виконання стрибків за м'ячем (сейв), а також антропометричних вимірюваннях. У дослідженні застосовано такі методики, як багатоступеневий фітнес-тест (човниковий біг), тест на визначення реакції воротаря та вправи на розвиток навичок виконання стрибків за м'ячем, а також вимірювання зросту та ваги. Для аналізу даних було застосовано t-критерій для визначення відмінностей у показниках між до- і післятестовим періодами з рівнем значущості менше 0,05 ($p < 0,05$).

Результати. Після 10 місяців тренувань з футболу у воротарів було зафіксовано значне покращення показників аеробної витривалості ($p = 0,004$), швидкості реакції ($p = 0,007$) та техніки виконання стрибків за м'ячем ($p = 0,002$). Однак не було встановлено значних змін у зрості, вазі та ІМТ, оскільки p-значення становило більше 0,05.

Висновки. Отримані результати мають важливе значення для оцінки програм підготовки воротарів і є основою для рекомендацій щодо впровадження більш ефективних тренувальних програм.

Ключові слова: воротарі, аеробіка, швидкість реакції, антропометрія.

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The Influence of Physical Activity on Stress-associated Conditions in Higher Education Students

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Abstract

Objectives. The purpose of the study was to substantiate the influence of physical activity on stress-associated conditions in higher education students.

Materials and methods. The dataset for building the models consisted of 1115 observations, 16 independent and 3 dependent variables. As the main method we used the random forest method, the idea of which is to obtain a forecast by aggregating the predictions of a set of individual decision trees, each of which is trained on a data subset isolated from the studied sample.

Results. Physical activity (PA) was found to be the most important factor in predicting stress-related conditions in university students. In addition, PA levels involving moderate and high levels of energy expenditure, as well as the number of stressful events experienced, played a significant role in predicting stress among students. In order to predict stress-related conditions in higher education students, the models "Stress", "Increased anxiety", and "Risk of PTSD" were built using the random forest method. The model "Stress" had the highest quality: its Accuracy was 0.77, Recall – 0.86, Precision – 0.79, and F1 Score – 0.82. The "PTSD Risk" model correctly predicted 78% of cases that indicates its good overall performance, however it correctly identified only 23% of the students who actually had the signs of this disorder. Regarding the state of anxiety, given that it is less stable than stress and PTSD, which can make model training difficult, the model built had an average accuracy of 56%, as well as reduced completeness and balance.

Conclusions. Models for predicting increased anxiety and identifying students with signs of PTSD require further improvement. The implementation of developed models allows to quickly identify the manifestations of stress-related conditions in higher education students and to take the necessary measures based on the engagement in PA to prevent the development of stress-related disorders.

Keywords: physical activity, stress, students, model, condition, health, random forest.

Introduction

Against the background of the action of stress factors of increased potential in the country, there is a significant prevalence of stress-related conditions (Pavlova et al., 2022; Vypasniak et al., 2023; Kurapov et al., 2023), namely stress, anxiety, and post-traumatic stress disorders (PTSD) among the students (Rogowska & Pavlova, 2023; Zaitsev, 2023; Meshko et al., 2023). Therefore, it has become an issue particularly actively discussed by experts in the different fields (Limone et al., 2022). Our previous research shows that the field of physical education (PE) also has an inexhaustible potential to help students counteract powerful stress factors (Andrieieva et al., 2023; Byshevets et al., 2022, 2023). So far, we have been able to make sure that the use of PA helps

students develop stress resistance, causes the development of resistance to anxiety, and prevents the emergence of post-traumatic stress disorders (PTSD). Therefore, the research aimed at identifying cases of stress-related conditions among students, and determining the most significant factors that influence their manifestation, will allow taking the necessary measures based on the use of PA and prevent the development of stress-related health disorders of students.

Modern scientists use methods of data mining based on artificial intelligence in their research, which includes machine learning, deep learning, natural language and image processing. The application of methods of data mining with the use of artificial intelligence methods allows for finding hidden patterns, trends, and interconnections, improving the decision-making process based on empirical data, rather than guided by intuition, and predicting the development of objects and events, etc. (Kim et al., 2022; Nachouki et al., 2023).

Data mining and machine learning have significant potential in the field of training specialists (Li & Wang, 2022). Scientists are convinced that the use of machine models makes it possible to determine the key factors affecting the success of learning, and contributes to a deeper understanding of the mechanisms and patterns of educational activity (Nachouki et al., 2023).

The research of Ding et al. offered an improved system for evaluating the educational achievements of university students in PE which is more objective compared to the traditional system (Ding et al., 2023).

The article written by Wang et al. (2022) presents information on the method of evaluating the quality of PE teaching and learning which is based on deep learning.

One of the methods of data mining, increasingly used by experts in various fields of knowledge, is the random forest (RF) method. This is one of the approaches to machine learning, which is based on the RF algorithm (Schonlau & Zou, 2020).

There is evidence of the successful application of the RF method in pedagogics for predicting students' academic performance. Thus, Nachouki et al. (2023), using the RF method, established that the last cumulative average score of a student is the most important factor determining their further educational achievements.

The results of the investigation indicate the successful application of the RF method in the practice of PE (Xu & Yin, 2021). In order to improve the quality of PE, these authors identified the factors affecting the success of students in PE, and based on the use of an improved iterative RF algorithm, constructed a model that allows predicting students' grades based on their scores for each factor. It should be noted that the accuracy of the proposed model reached 88.55%.

J. Briand introduced a data mining system to predict injuries to athletes during the next 7-day training microcycle. The constructed models allow correctly predicting more than 50% of future injury days and more than 70% of future injury-free days (Briand et al., 2022).

Jiang (Jiang et al., 2023) also used the RF method to improve the assessment of the quality of PE teaching. The use of this model makes it possible to determine the weaknesses and strengths of students, identify learning problems, and provide appropriate recommendations (Jiang et al., 2023).

There is also some evidence of the use of the RF model to classify stress based on the personal characteristics of employees with an accuracy of up to 81% (Kim et al., 2022). However, despite the significantly greater predictive power of the RF compared to the single decision tree, researchers faced the problem of the complexity of interpreting the constructed models. This significantly limits their use in PE research.

Materials and Methods

Study Participants

The presented study analyzed the results of a survey of 1115 students from different regions of Ukraine for 2022-2023. Among the respondents, 42.8% were male students, and 57.2% were female students; 40.2% indicated a negative experience of being in the epicenter of hostilities. The average age of the respondents was 20.0±3.9 years. During the hostilities, higher education students experienced from 0 to 9 stressful events, the median indicator was 2 (1; 3) cases. The research was carried out in accordance with bioethical requirements.

Study Organization

The PA of students was measured according to the short International Questionnaire on PA (IPAQ, 2016), in points; the stress was measured according to the questionnaire of Shcherbatykh (Shcherbatykh, 2002), in points; the reactive anxiety was measured according to the Spielberger-Hanin test (STAI), in points; the signs of PTSD were measured according to the Mississippi scale for the assessment of post-traumatic reactions (civilian version) (Sloan et al., 1995), in points. The data set consisted of 1115 observations. Each data observation had 16 attributes. Among them, the categorical ones are gender, direction of education, negative experience, and strengthening of unhealthy habits. The rest includes the number of stressful events, PA, sleep, mood, etc., which are quantitative attributes.

The description of the input data is given in the table (Table 1).

Dichotomous variables were used as dependent signs that characterized the existing manifestations of stress-related conditions, in which stress (stress score exceeded 12 points), increased anxiety (anxiety score exceeded 45 points), and signs of PTSD (PTSD score exceeded 100 points) were assumed as 1, and their absence – as 0, for particular models. In total, 63.9% of respondents had stress, 41.5% had increased anxiety, and 23.0% had the symptoms of PTSD.

Statistical Analysis

The ensemble method of machine learning – the RF method – was chosen as the key research method. This method is a powerful tool for classification and regression modeling and is a machine learning algorithm aimed at reducing variance and overtraining, as well as evaluating the importance of variables. The RF method was used to predict the stress-related condition of students, namely increased stress, anxiety, and the presence of PTSD symptoms.

The implementation of the RF method involves the generation of a set of random subsets from the data set, for each of which a decision tree is constructed. In the process

Table 1. Description of input data

Predictors	Description	Range of values	Encoding
V1	Sex	male / female	1/0
V2	Field of education	physical education and sport / other	1/0
V3	Negative experience	was in the epicenter of hostilities/was not	1/0
V4	Number of stress events	0~10	Without encoding
V5	Increase of bad habits	No/Somewhat not/Somewhat yes/Yes	1/2/3/4
V6	PA	7~42	Without encoding
V7	PA with high energy expenditure	0~14, points	Without encoding
V8	PA with moderate energy expenditure	0~14, points	Without encoding
V9	PA with low energy expenditure	0~14, points	Without encoding
V10	PA with minimal energy expenditure	0~7, points	Without encoding
V11	Activity	1~5, points	Without encoding
V12	Sleep	1~5, points	Without encoding
V13	Mood	1~5, points	Without encoding
V14	Appetite	1~5, points	Without encoding
V15	Physical working capacity	1~5, points	Without encoding
V16	General health condition	1~5, points	Without encoding

of constructing RF trees, a non-linear approach is used to identify interconnections between attributes, which allows identifying a wider range of attributes (Nachouki et al., 2023). Each decision tree makes a prediction for new data, and the final prediction in our case is determined by the majority of votes (Fig. 1).

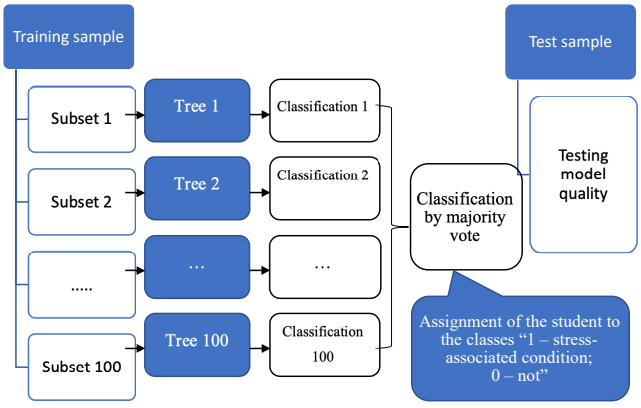

Fig. 1. Application scheme of the RF algorithm

This makes the model more resistant to overtraining and improves its generalization ability.

Model parameters. The construction of models was carried out by sequentially adding decision trees. Each RF consisted of 100 decision trees. The number of random indicators (predictors) is 5. The depth of each tree in a node did not exceed 10 levels, and each node could be split into two child nodes only if at least 5 observations were concentrated in it (according to the previous split, at least 5 higher education students were placed in it). The leaves of the tree are nodes that do not have child nodes and make decisions about the class that the object belongs to (Fig. 2).

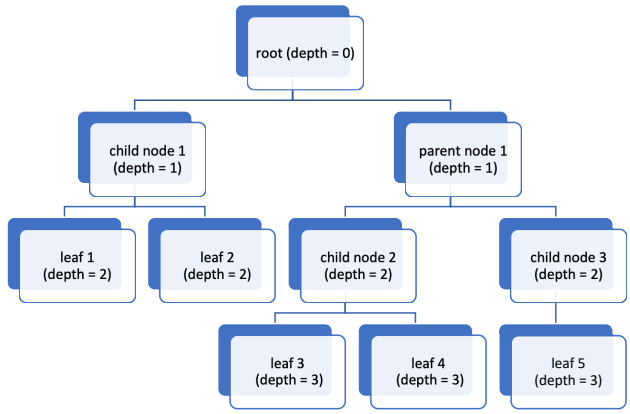

Fig. 2. Decision tree structure diagram in a random forest

This setting of parameters allows for simplifying the models and prevents them from being overtrained.

Model training. To train the model, there was randomly selected 50% of the data from the proposed data set. The construction of each decision tree involved the random selection of 5 attributes from 16 independent variables.

Assessment of accuracy. The accuracy of the model was checked on the basis of 30% of the observed data that did not participate in the training.

In the course of assessing the accuracy of the models, there were constructed 2×2 classification matrices. On the main diagonal of each matrix there are the results of calculations of correctly classified students: true positive (TP) and true negative (TN), where TP can be considered as an "alarm signal", that is, the classifier detects a student with a stress-related condition. The remaining 2 elements are the number of incorrectly classified cases – false positive (FP) and false negative (FN). The accuracy of models can be

calculated with the help of appropriate formulas (Xu & Yin, 2021). As a result, the following metrics were used to assess the quality of the models:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$\text{Recall} = \frac{TP}{TP + FN} \quad (2)$$

$$\text{Precision} = \frac{TP}{TP + FP} \quad (3)$$

$$\text{F1 Score} = \frac{2 \cdot \text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}} \quad (4)$$

To implement the tasks, the STATISTICA program (StatSoft, USA) was used, which made it possible to automate the process of constructing a RF.

Results

As shown by the results of previous research (Andrieieva et al., 2023; Byshevets et al., 2023), the level of stress-related conditions of students is determined by numerous factors, including controlled and uncontrolled ones. Some of them increase the risk of stress-related conditions of students, while others allow them to counteract the negative consequences of stress factors. Among the uncontrollable factors, it is possible to point out the gender of students, since, according to literature sources, for female students, it is more difficult to experience the impact of stress factors compared to male students. In addition, another uncontrolled harmful factor can be a negative experience, which comes from being in the epicenter of hostilities; and a positive one is the direction of education, where we assumed that higher education students in the specialty Physical culture and sport are more engaged in PA. Among the controlled factors increasing stress-related conditions of students, there can be addictive behavior, sedentary lifestyle, etc., and the factors that contribute to counteraction to stress include PA classes, adaptive ways of behavior, etc.

We constructed three models aimed at predicting stress-related conditions of students. Figure 3 shows the process of constructing a RF for predicting the stress of students, where the horizontal axis represents the number of trees, and the vertical axis represents the proportion of classification errors for the training and test samples. The research showed that despite the construction of 100 trees, the process relatively stabilized after 30 trees. The proportion of classification errors ranges from 0.19 to 0.33 (Fig. 3).

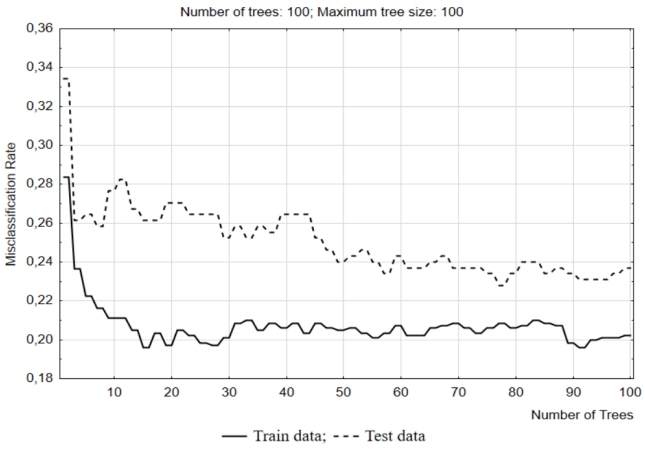

Fig. 3. The process of constructing a random forest (n=1115)

The program allows viewing individual decision trees in a RF (Fig. 4).

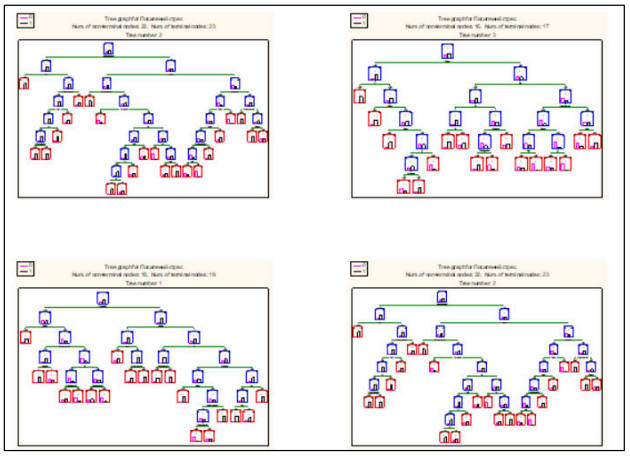

Fig. 4. An example of individual decision trees for predicting stress of higher education students

The research made it possible to define the most significant indicators for the prediction of stress in students. The main indicator was their PA. Such indicators as PA with high energy consumption; PA with moderate energy consumption, and the number of stressful factors topped the ranked list of significant features characterizing students. Meanwhile, despite our assumptions, gender, negative experience and the direction of education are at the end of the rating of significant factors for the prediction of stress of students (Fig. 5). Similarly, we constructed and analyzed a prediction model for increased anxiety and PTSD symptoms.

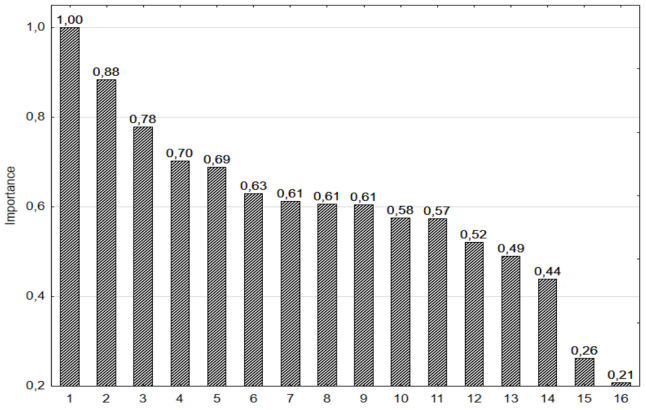

Fig. 5. Importance plot (n=1115). Note: 1 – PA; 2 – PA with high energy expenditure; 3 – PA with moderate energy expenditure; 4 – the number of stressors; 5 – general health condition; 6 – PA with low energy expenditure; 7 – bad habits; 8 – mood; 9 – PA with minimal energy expenditure; 10 – physical working capacity; 11 – appetite; 12 – activity; 13 – sleep; 14 – sex; 15 – negative experience; 16 – field of education

Table 2. Risk estimates for the constructed models

Models	Stress		Increased anxiety		Risk of PTSD	
Samples	Risk Estimate	Standard error	Risk Estimate	Standard error	Risk Estimate	Standard error
Training	0,204	0,014	0,331	0,017	0,187	0,014
Test	0,231	0,023	0,438	0,027	0,216	0,023

Table 3. Matrices of error classification and accuracy assessment of the built models (based on the test sample)

Models	Class / Observed	Class Predicted		Model quality indicators			
		0	1	Accuracy	Recall	Precision	F1 Score
Stress	Observed 0	77	47	0.77	0.86	0.79	0.82
	Observed 1	29	176				
Increased anxiety	Observed 0	175	3	0.56	0.07	0.77	0.12
	Observed 1	141	10				
Risk of PTSD	Observed 0	240	10	0.78	0.23	0.64	0.34

Table 4. Analysis of the significance of indicators of the stress-related condition of higher education students

Indicators of stress-related condition	The most important variables (>0.7)	The least important variables (<0.5)
Stress	PA; PA with high energy expenditure; the number of stress events; PA with moderate energy expenditure	appetite; sex; field of education; negative experience;
Increased anxiety	PA with moderate energy expenditure; PA; PA with high energy expenditure; PA with low energy expenditure; bad habits; the number of stress events; PA with minimal energy expenditure; physical working capacity	field of education; negative experience; sex;
Risk of PTSD	PA with high energy expenditure; the number of stress events; PA; general health condition; PA with moderate energy expenditure; PA with low energy expenditure; bad habits;	field of education; sex; negative experience;

The Risk Estimate calculations showed how likely it is that the proposed models will give an incorrect prediction. Since the Risk Estimate in all cases turned out to be smaller for the training sample than for the test one, it can be asserted that the constructed models passed cross-checking (Table 2).

The data on classification matrices and model quality assessments is presented in the table (Table 3).

The stress detection model turned out to be the best among the constructed models. It shows good results according to all metrics: with its help, in 77% of cases, it is possible to predict the presence or absence of stress in higher education students. The model correctly identifies 86% of cases of the stress of students, and in 79% of cases, it identifies the stress of a student when it is actually present. The F1 score indicates the balance of the model.

As for the "Anxiety Increase" model, despite its average accuracy of 56%, its completeness of 7% is low, which indicates a reduced ability of the model to determine a student with increased anxiety, which means that in 93% of cases, the students experiencing anxiety are classified as those who feel no anxiety. In contrast, in 77% of the cases when the model identifies increased anxiety in students, they actually experience increased anxiety, and a low F1 Score indicates that the model is not sufficiently balanced.

The "PTSD Risk" model correctly predicts 78% of all cases. However, the model is not good enough at identifying students with PTSD symptoms. That is, the model correctly identifies students with the signs of PTSD only in 23% of cases, and in the remaining cases, it identifies them as having no PTSD signs. In 64% of all the cases when the model identifies the students as those having PTSD symptoms, the students are actually characterized by the specified symptoms. The F1 score of 0.34 (or 34%) indicates that the model is sufficiently balanced, but it still can be much improved.

The analysis of indicators significant for the prediction allowed us to make sure that negative experience, gender, and the direction of education in the models of classification of higher education students, taking into account their PA, are the least important variables. At the same time, the general assessment of PA and PA with high energy consumption turned out to be among the first and most important variables for establishing the fact that a student has a stress-related condition (Table 4).

It is worth emphasizing that the program allows saving the PMML deployment codes for the created models for further use of these codes through the Rapid Deployment Engine module for the purpose of predicting the stress-related condition of higher education students who did not participate in previous research. In fact, we are talking about developing a prediction for new observations based on the proposed models.

Discussion

The research proved that the scientific community is actively searching for innovative methods and approaches

to improving the process of PE of students. The authors turn to progressive ideas, i.e. the application of data mining to identify patterns and predict objects and phenomena in the field of PE (Andrieieva et al., 2022; Jinpeng & Le, 2022; Li & Wang, 2022). Scientists convincingly prove that models constructed on the basis of regression or classification algorithms, which learn from regularities in accumulated data, are more productive and accurate for constructing predictions in the field of PE (Briand et al., 2022; Jiang et al., 2023). Among such algorithms, the RF method is gaining more and more recognition. This method has several advantages compared to a single tree (Documentation for TIBCO Statistica, 2024; Xu & Yin, 2021; Schonlau & Zou, 2020). The analysis indicates that predictive models constructed by the RF method are used to predict the academic achievements of students in the field of PE. This approach to assessment is not only more objective than the traditional one but also provides an opportunity to better understand the significant factors influencing educational achievements in the discipline and to gain a deeper understanding of the patterns of educational activity, allows timely corrections to be made in the process based on the predicted educational effect (Jiang et al., 2023; Li &Wang, 2022; Nachouki et al., 2023; Palczewska et al., 2013). It is worth pointing out that today there is some evidence of higher performance of models implemented by the RF method compared to other approaches (Li &Wang, 2022). However, the complexity of interpreting the results of applying the RF method often prevents its wide use in applied research on PE.

The RF method generating a prediction by combining the predictions of a group of decision trees, which allows for significantly increasing its accuracy compared to other methods based on the construction of a decision tree, can be a modern powerful tool for predicting the stress-related condition of students (Li &Wang, 2022; Ding et al., 2022).

It was found that the stress-related conditions of students are most influenced by the PA of students, including PA with high and moderate energy consumption and the number of stressful events they have encountered. These variables were the most significant for predicting stress, increased anxiety, and PTSD symptoms in students.

The fact that gender did not turn out to be a significant factor affecting the stress-related condition of the category of youth under research was an interesting and unexpected result for us. This contradicts not only the data given in scientific sources (Pavlova et al., 2022; Rogowska &Pavlova, 2023; Levin et al., 2022; Petrachkov et al., 2023) but also our previous research where we found that female students reported symptoms of stress-related conditions more often than male students (Andrieieva et al., 2023; Byshevets et al., 2023). It is important to note that in previous research, either a separate comparative analysis of indicators of stress-related conditions depending on gender was carried out, or there was used the data obtained by respondents' reporting on the regularity of their activity (No/Rather not/Rather yes/Yes), but the results of measuring the level of their PA according to the IPAQ were not taken into account. The construction of logistic models does not allow taking into account gender or other categorical variables. In addition, the data sets were significantly smaller. Thus, we have every reason to believe that gender is not the only or the main factor affecting stress-related conditions in students. There are other variables that may moderate or mediate the connection between gender and stress. One of these variables is the level of PA which can mitigate the effects of stress factors, as indicated by the results of numerous scientific research, including ours (Andrieieva et al., 2022,2023; Byshevets et al., 2023; Kashuba et al., 2021; Steinacker et al., 2023). Therefore, due to the equally positive impact on stress regardless of gender, physical activity can be a factor that alleviates differences in the reaction to stress factors between students of different genders. Perhaps this is why, when we added quantitative indicators of PA to our model, gender ceased to be a significant factor for predicting stress-related conditions of students. This can mean the following:

- PA is a more significant factor influencing the formation and development of a stress-related condition in students than gender;
- gender indirectly affects the stress-related condition of students through PA, i.e., PA is actually a mediator for establishing the mechanism of gender influence on the stress-related condition of students;
- the connection between gender and the stress-related condition of students depends on the moderator – another variable, for example, the direction of education or the negative experience of being in the epicenter of hostilities, which interact with each other and have different effects on their stress-related condition.

Conclusions

Against the background of the continuation of the armed conflict in Ukraine, cases of stress-related conditions are becoming more and more frequent among students. An important task in the field of PE and sports is the prompt identification of students characterized by a stress-related condition. This will make it possible to offer them appropriate measures based on the use of means of PA to mitigate the negative effects of stress factors of increased potential and to prevent the development of stress-related disorders.

It was established that PA is the most important feature that allows the prediction of stress-related conditions in students. In addition, indicators of PA with moderate energy consumption, PA with high energy consumption, as well as the number of stressful events experienced by students are important for predicting stress in students. We constructed the "Stress", "Increased anxiety" and "Risk of PTSD" models, aimed at predicting stress-related conditions of students, using the RF method. The models for predicting increased anxiety and identifying students with PTSD symptoms require further improvement.

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Conflict of interest

The authors declare no conflict of interest.

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Вплив рухової активності на стресасоційовані стани студентів закладів вищої освіти

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Реферат. Стаття: 9 с., 4 табл., 5 рис., 31 джерело.

Мета дослідження – обґрунтувати вплив рухової активності на стресасоційовані стани студентів закладів вищої освіти.

Матеріали та методи. Набір даних для побудови моделей складався з 1115 спостережень, 16 незалежних і 3 залежних змінних. В якості основного методу використали метод випадкового лісу, ідея якого полягає в тому, щоб отримати прогноз шляхом агрегування прогнозів набору окремих дерев рішень, кожне з яких навчається на підмножині даних, виділених із досліджуваної вибірки.

Результати. Встановлено, що найважливішим фактором прогнозування стресових станів у студентів є їх рухова активність (РА). Крім того, значну роль у прогнозуванні стресу в студентів відіграють рівні РА, що включають помірні та високі рівні витрат енергії, а також кількість пережитих стресових подій. Для прогнозування стресових станів у студентів вищої освіти за методом випадкового лісу побудовано моделі «Стрес», «Підвищена тривожність», «Ризик ПТСР». Модель «Стрес» мала найвищу якість: її точність склала 0,77, пригадування – 0,86, точність – 0,79, оцінка F1 – 0,82. Модель «Ризик посттравматичних стресових розладів» правильно передбачила 78% випадків, що вказує на її хороші загальні показники, однак вона правильно ідентифікувала лише 23% студентів, які насправді мали ці ознаки. Що стосується стану тривоги, враховуючи те, що він менш стабільний, ніж стрес і посттравматичний стресовий розлад, що може ускладнити навчання моделі, побудована модель мала середню точність 56% і знижувала повноту та збалансованість.

Висновки. Моделі прогнозування підвищеної тривожності та виявлення студентів з ознаками ПТСР потребують подальшого вдосконалення. Розроблені моделі дозволяють оперативно ідентифікувати прояви стресових станів у студентів вищої освіти та на основі використання РА вживати необхідних заходів для запобігання розвитку стресових розладів.

Ключові слова: рухова активність, стрес, студенти, модель, стан, здоров'я, випадковий ліс.

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The Effects of Fatigue on Landing Performance in Young Female Soccer Players

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Abstract

Objectives. Jumping and landing constitute two movements that are used with a very high frequency in all sports and are two skills that have received a lot of attention in the literature because of their relationship with injury risk. The aim of this study is to analyze the following aspects: (a) to determine whether fatigue negatively affects landing technique after a jump, and (b) to test whether different metabolic and neuromuscular exercises have an effect on the landing technique.

Materials and methods. The sample is composed of young female soccer players Under 14 (n = 29, 13.06 ± 1.27 years, 47.8 ± 2.6 kg; 143.2 ± 3.4 cm). Before and after two training protocols aimed at determining the state of fatigue (functional agility short-term fatigue protocol, and RSA protocol), landing technique was assessed using the Landing Error Scoring System (LESS).

Results. The LESS assessment for the pre-fatigue and post-functional agility short-term fatigue protocol conditions showed a value of 6.78 ± 0.81 and 8.74 ± 0.77 respectively ($p > 0.001$, ES: 1.39). The LESS assessment for the post-RSA protocol condition was 8.52 ± 0.87; this score was statistically significantly higher than the pre-fatigue condition ($p > 0.001$, ES: 1.24).

Conclusions. Intensive exercise, both neuromuscular and metabolic, appears to have an effect on the landing technique of young female soccer players.

Keywords: landing, young female soccer players, injury prevention, fatigue.

Introduction

The process of developing motor skills related to basic fundamental movements such as jumping or running has been related to the possibility of increasing the quantity and quality of motor experiences in developmental age (Tsuda et al., 2020; Gao et al., 2021; Ceruso et al., 2019; Esposito et al., 2019).

The period within which most children develop fundamental movements is completed around puberty, while thereafter the process of refinement begins, spanning into adulthood (D'Elia et al., 2023; Angulo-Barroso et al., 2022; D'Isanto et al., 2021; Lima et al., 2019).

Within the classification of basic functional movements, jumping appears but ground landing, which is the complementary and subsequent movement to jumping, is not mentioned (Chow et al., 2020).

In fact, in sports, athletes resort to jumping, almost always maximal (Ziv & Lidor, 2010), from about 18-23 times per set in volleyball (Lima et al., 2019), to 12-43 jumps in women's basketball depending on the roles on the court (Scanlan et al., 2012; Reina Román et al., 2019), to 21-45 jumps per contest in women's beach volleyball (Natali et al., 2019).

Often, the landing strategy can also vary, and for some Authors, about 50 percent of ground contact holds are performed in one-leg (Tillman et al., 2004).

Almost always these maximal jumping and landing movements occur in a competitive context where metabolic demands, and consequently central and peripheral fatigue

levels, are high (Batalla-Gavalda et al., 2023; Choi & Joo, 2022; Vescovi et al., 2021; Esposito & Raiola, 2020).

Particularly in women's soccer, performance differences are observed when comparing young female soccer players and elite female soccer players, leading to the hypothesis that jumping skills are not sufficiently enhanced in the training of female athletes (Castagna & Castellini, 2013).

Data on girls' participation in sports around the world indicate an incremental trend in recent years (Fink, 2015): between 58% in the United States and 21% in Europe (Deng & Fan, 2022; Kwon et al., 2021; Emmonds et al., 2021) are approaching competitive sports so it seems of great relevance to turn attention to the different phases of jumping.

In fact, jumping and landing constitute two movements that are used with a very high frequency in all sports and constitute two skills that have been highly attented in the literature because of their relationship with injury risk (Song et al., 2023; Chijimatsu et al., 2020; Bates et al., 2019).

In fact, it is known how the knee injuries, and anterior cruciate ligament injuries in particular, take on epidemiological significance when looking at the occurrence of such injury in the female population participating in sports (Mandorino et al., 2023; Di Paolo et al., 2023; Larwa et al., 2021; Hägglund & Waldén, 2016).

And great occirence has no-contact injuries in the knee for young female athletes especially in the pre-puberty period (Edison et al., 2022).

Therefore, evaluation of landing technique becomes an indispensable time to intervene in training sessions and introduce effective compensatory exercises for young female athletes (Limroongreungrat et al., 2022; Okoruwa et al., 2022; Beese et al., 2015, Root et al., 2015).

In particular, the differences in Ground Reaction Force (GRF) in the landing phase between adults and youth are known to lead to bias towards the landing technique itself (Bassa et al., 2022).

The Landing Error Score System (LESS) constitutes an effective and validated diagnostic assessment tool to investigate two-legs landing technique in sports (Limroongreungrat et al., 2022; Okoruwa et al., 2022; Fox et al., 2016, Padua et al., 2015).

The total score obtained through the LESS is a valid predictor of lower limb injury (Rostami et al., 2020; Root et al., 2015)

In fact, through this test it is possible to analyze landing motion and know which positions present mechanics that may be a risk factor for the lower limb (Jimenez-Garcia et al., 2023; Barber-Westin & Noyes, 2017; Root et al., 2015).

The literature through systematic reviews has investigated how fatigue alters landing technique (Santamaria & Webster, 2010) in individuals who are engaged in a return-to-play process (Peebles et al., 2021; Gokeler et al., 2014), in young college athletes (Zhang et al., 2021), in basketball players (Liveris et al., 2021), in female collegiate athletes over 19-years old (Cortes et al., 2012) or during different landing techniques (Heebner et al., 2017).

To date, analysis of the effects of fatigue on landing technique has focused on activities very specific to the sports considered, such as simulated matches or high-intensity exercise (Peebles et al., 2021; Liveris et al., 2021, Vermeulen et al., 2023).

And studies have mainly focused on sports that are performed indoors with a consistently even surface, while sports that are performed outdoors with weather conditions that can vary and affect the firmness and evenness of the playing surface have not been considered (Zhang et al., 2021; Heebner et al., 2017).

Therefore, an open problem remains in the literature: namely, understanding how landing technique can be affected by sport-specific movements in young female soccer players.

Indeed, the performance model imposes a number of metabolic and neuromuscular demands on young female soccer players that could alter the execution technique of some soccer-specific skills.

This study aims to (a) analyze landing technique in young female soccer players, (b) understand whether fatigue negatively affects landing technique, and (c) test whether different metabolic and neuromuscular exercises affect landing technique.

Material and Methods

Partecipants

The 29 participants (average age:13.06±1.27 years, weight: 47.8±2.6 kg; height: 143.2±3.4 cm) were youth female soccer players who competed in élite soccer schools in Italy. Participants were included if they were aged 11–13 years old and had been training for soccer training and competition for at least 2 years. Participants were excluded if they had sustained a musculoskeletal/joint injury within the previous 3 months prior to commencing experimental testing or encountered any other injury that could obstruct their performance at the assessment time.

The study was approved by the club's manager, by FIGC (Federazione Italiana Giuoco Calcio) regional ethics committee and was performed according to the principles expressed in the Declaration of Helsinki. The written informed consent was obtained from the parents, while the young female soccer players have signed the informed assents.

Procedures

The two protocols aimed at achieving a fatigue condition were proposed at the same time (3.30 PM) and 72 hours apart to avoid biasing the assessments.

For both protocols, the same warm-up (15 minutes) consisting of a running phase at 60% of HRmax (6 minutes), a lower extremity and trunk mobility phase (4 minutes), and a special and soccer-specific running phase (5 minutes) was provided.

At the end of the warm-up, the LESS test was performed under pre-fatigue conditions.

The LESS protocol involves a jump onto a landing zone from a 30 cm box at a distance equal to 50% of the individual's height, followed by a maximum vertical jump (Beese et al., 2015).

The LESS provides for 17 scored items to assessment the landing from both the sagittal and frontal views. The LESS test score is based on the detection of errors on a number of easily observed markers of the jump-landing movement. A higher LESS score indicates more errors and, therefore, modest landing and jumping technique. In

agreement with previous research (Beese et al., 2015), LESS scores are categorized for the specific population observed and are defined as excellent (0-3 points), good (4-5 points), moderate (6 points), and poor (>7 points).

The execution of the test should be videotaped, ensuring that the two cameras are placed to detect movements in the frontal and sagittal planes (Liveris et al., 2021).

The cameras were mounted on tripods and placed in front and to the side of the jump box and landing area. The lens height of each camera was 121.92 cm from the floor and 345.44 cm from the landing area, in agreement with previous research (Fig.1).

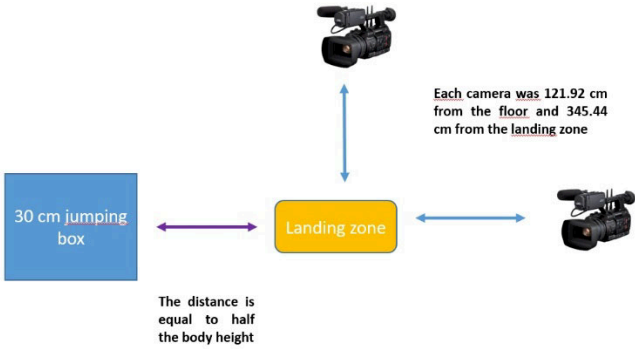

Fig. 1. Landing Error Scoring System data-collection setting

The sample was randomly assigned in a 1:1 ratio to a functional agility short-term fatigue protocol or to a Repetead Sprint Ability (RSA) protocol. Then, each participant followed a) a functional agility short-term fatigue protocol (Cortes et al., 2012), implemented by other soccer-specific skills, b) the RSA protocol (volume: 360 meters).

The functional agility short-term fatigue protocol included: step-ups on a 30-cm box, diagonal run exercise, an "L-drill" exercise (Carvalho et al., 2017), n.5 countermovement maximal jumps with hands bound at the hips, running back and forth on a speed ladder, and a 5-0-5 run.

The functional agility short-term fatigue protocol involved the following succession of exercises: a series of step-up movements on a 30 cm high step for 20 seconds with the metronome set at 160 bpm (McLean et al., 2007); then they performed a repetition of fast "L-drill" running; then they performed diagonal maximal speed run in 6 stretches of 5 meters; after that they performed 5 maximal and consecutive CMJs. After the CMJs they would perform the ladder agility exercise.

The sequence of running patterns on the speed ladder (3 meters) were required as follows: in the first and second repetitions, they touched with both feet in each space of the ladder, while in the third and fourth repetitions, a lateral run (once to the left and once to the right) was required, with both feet touching each space of the speed ladder with a metronome set at 180 bpm (McLean et al., 2007). Each set included the four agility speed ladder drills.

Lastly, they performed 5-0-5 drill at maximal speed run (Tab.1) .

Participants had to perform a total of four sets of the fatiguing protocol with no rest between the sets. Four sets were chosen based on similar research in the literature that has been shown to induce an effective fatiguing state (Cortes et al., 2012).

Table 1. Sequence of exercises introduced in the functional agility short-term fatigue protocol (this sequence was repeated for 4 sets)

Functional agility short-term fatigue protocol (sequence of the exercises)	
1)	Step-up on a 30 cm high step for 20 seconds (at 160 bpm - metronome)
2)	L-drill running at maximal speed
3)	Diagonal maximal speed run in 6 stretches of 5 meters
4)	5 maximal and consecutive CMJs
5)	4 repetitions of running on speed ladder of 3 meters (at 180 bpm – metronome)
6)	5-0-5 drill at maximal speed run

The RSA protocol (Gabbet, 2010; Lockie et al., 2020; Bishop et al., 2011) involved performing 6 repetitions of 20 m (15 seconds after every 20 m and 3 minutes after the 6 repetitions); this exercise was repeated for 3 sets for a total of 360 m (Tab.2). All exercises were performed requiring all-out intensity.

Table 2. Sequence of exercises introduced in the RSA protocol

Repetead Sprint Ability protocol
1) 20 meters × 6 (rest:15 sec)
Rest 3 minutes
2) 20 meters × 6 (rest:15 sec)
Rest 3 minutes
3) 20 meters × 6 (rest:15 sec)
Rest 3 minutes

During the functional agility short-term fatigue protocol and RSA protocol, participants used wireless heart rate (HR) monitors equipped with a telemetry system (Polar Electro Oy, Kempele, Finland) to detect the exercise sequence intensity (peak HR, and a percentage referred to the maximum HR (%HRmax).

At the end of the protocol they reported the RPE value using the CR10 Borg Scale.

To be considered in a fatigued condition, subjects' heart rate had to be at a minimum of 80% of their estimated maximum heart rate.

Immediately upon completion of functional agility short-term fatigue or RSA protocol, participants again performed the LESS post-fatigue assessment.

Statistical Analysis

At first, descriptive statistics analysis was performed. Then, a t-test for dependent samples was carried out, using the level of significance at $p < 0.05$. The evaluation of the effect prior to and post- short-term fatigue protocol for the

tested hypothesis was estimated using the Cohen's d method (Cohen, 1992): as for the effect size index (Effect Size), after calculating the δ index it is possible to convert it into Effect Size: ≤ 0.20 small; 0.50 average; ≥ 0.80 large.

Statistical analyses were performed using the software Statistical Package for Social Sciences (SPSS 22.0 for Windows).

Results

The LESS assessment for the pre fatigue and post functional agility short-term fatigue protocol condition respectively showed a value of (mean ± ds) 6.78±0.81 and equal to 8.74±0.77 (p>0.001, ES: 1.39).

The load intensity determined by the functional agility short-term fatigue protocol resulted in a peak HR value of 178.76±6.55 bpm and a %HR of 85.04±4.66%.

Load assessment by CR10 Borg Scale showed a value of 7.59±0.68.

The LESS assessment for the post RSA protocol condition showed a value of (mean ± ds) 8.52±0.87; this value was statistically significantly higher than the pre fatigue condition (p>0.001, ES: 1.24).

The load intensity determined by the RSA protocol resulted in a peak HR value of 174.55±4.65 bpm and a %HR of 84.17±6.16%.

Load assessment by CR10 Borg Scale showed a value of 7.55±0.69.

No statistically significant difference was observed between the LESS, peak HR, %HR and CR-10 Borg Scale values in the two post-fatigue conditions.

The values are summarized in Table 3.

Discussion

The aim of the study was to analyze the landing technique in young prepubescent female soccer players. In addition, the study wanted to test whether different protocols aimed at the onset of fatigue could affect landing strategies in young female soccer players.

To the knowledge currently available in the literature, this is the first study that turns attention toward landing technique under fatigue conditions in female youth soccer.

Monitoring the execution technique of certain sport-specific skills such as stopping or landing takes on a strong relevance in the young athlete training, especially if the athlete is a young female soccer player. In fact, the literature points out that age and gender are two factors that condition lower limb motion patterns between 11-16 years old (Shultz et al., 2022; Otsuki et al., 2021; Yu et al., 2005).

Comparison of values obtained in the LESS under resting conditions and post functional agility short-term fatigue protocol showed a statistically significant decrease in landing technique in young female soccer players with a large ES.

A similar result was observed when comparing LESS values under resting conditions and LESS values after the RSA protocol with a large ES.

No statistically significant difference emerged between the two post-fatigue conditions.

The values obtained after the execution of the two protocols aimed at achieving a fatigue state in young female soccer players should direct attention toward the landing technique, so far modestly investigated in the literature in young female athletes (Angulo-Barroso et al., 2022; Zhang et al., 2021).

In this regard, the literature highlights how landing technique is sport-specific in young athletes and how this varies in relation to the sport played especially in prepubertal age (Estevan et al., 2020).

In particular, young female soccer players are engaged in an activity that involves high exercise intensities, frequent changes of direction, and jumps that induce high peripheral and central fatigue (Vescovi et al., 2021; Esposito & Raiola, 2020).

In this direction, the literature argues that fatigue adversely affects some risk factors by showing a reduction in muscle strength, joint control and stabilization, and a reduction in joint position sensation (Verschueren et al., 2020; Vermeulen et al., 2023).

This reduction in postural and joint control represents a worrisome picture for lower limb injury risk because it is known to what extent landing can be affected by the misalignment of different body segments (Vermeulen et al., 2023; De Blaiser et al., 2018; De Ridder et al., 2015).

For example, trunk flexion appears to influence GRF in landing, the proximal segments being crucial in the execution and control of jumping and landing, just as lateral trunk flexion substantially changes the load on the two lower limbs (De Bleecker et al., 2020; Chuter & Janse de Jonge, 2012).

The performance decrease in the control of the landing technique in the two intense exercise conditions between 25% and 29% leads to the hypothesis of a marked influence of fatigue on this phase of the jump in young female soccer players.

The two intense exercise conditions proposed to the participants met the inclusion criteria because they showed a value of 80% HR but it should be remembered how competitions involve cardiovascular stresses even

Table 3. Values of the LESS test and internal load parameters measured under the observed conditions

Indicators	Pre-fatigue	Post- functional agility short-term fatigue protocol	p value	ES	Post - RSA protocol	p value	ES
LESS	6.78±0.81	8.74±0.77	0.0004	1.39	8.52±0.87	0.0005	1.24
FC peak		178.76±6.55			174.55± 4.65		
% HR		85.04±4,66			84.17±6,16		
CR-10 Borg Scale		7.59±0.68			7.55±0.69		

higher than this value; and that the state of fatigue that may be established could be even greater than the condition presented in this study (Choi & Joo, 2022; Vescovi et al., 2021; López-Valenciano et al., 2021).

Therefore, the role of fatigue on landing technique calls for a careful analysis in young prepubescent female athletes in light of the knowledge derived from the literature: in fact, maturation results in some gender differences in both vertical jump performance and landing ability, where girls are unable to reduce GRF during landing in drop jump trials (Larkin et al., 2023; Holden et al., 2016; Quatman et al., 2006).

The other purpose of the study was to understand whether different protocols aimed at the onset of fatigue could affect landing technique.

The functional agility short term fatigue protocol presented agility and neuromuscular exercises, while the RSA protocol was structured only with sprints followed by incomplete recovery. The former aimed to present all types of demands that occur in competition, while the latter aimed to stress young female soccer players metabolically.

Looking at peak HR values, HR percentages, and CR 10 Borg scale values, the two protocols resulted in very similar engagement: just this similarity for the internal load observed, the two protocols very similarly influenced the values and landing technique in the LESS post protocol.

The values obtained in LESS post fatigue were very similar to those obtained from previous studies even with different samples (Liveris et al., 2021; Gokeler et al., 2014; Cortes et al., 2012).

Moreover, they are consistent with what has been observed in GRF during drop jumps performed under fatigued conditions by young soccer players: the GRF increases significantly under fatigued conditions, due to the reduced ability to attenuate the impact in the landing phase (Oliver et al., 2008).

Conclusions

In conclusion, intense exercise appears to affect landing technique in young female soccer players, both when neuromuscular exercises are presented and when the exercises are metabolic.

Knowing the behavior of young female soccer players during the landing under fatigue conditions can help staffs schedule training sessions more carefully: for example, it might be less risky to place the most intense drills at the end of the session; or, to provide a low-intensity technical drill after planning a small-sided games or a high-intensity metabolic phase.

Further studies will be able to implement this analysis by observing what happens during an official competition or during a tournament involving close matches with few hours of recovery.

In addition, it will be very interesting to expand the study by involving female athletes and soccer players at post-puberty age to understand whether training age or maturation can improve landing technique under fatigue conditions.

Conflict of Interest

The authors declare no conflict of interest.

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Вплив втоми на ефективність виконання приземлення у юних футболісток

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 3 табл., 1 рис., 69 джерел.

Мета дослідження. Стрибок і приземлення представляють собою два види рухів, що використовуються з дуже високою частотою у всіх видах спорту, і є двома навичками, яким приділяється значна увага в літературі через їх взаємозв'язок з ризиком травмування. Метою цього дослідження є аналіз наступних аспектів: (a) визначити, чи має втома негативний вплив на техніку приземлення після виконання стрибка, і (б) перевірити, чи впливають різні метаболічні та нервово-м'язові вправи на техніку приземлення.

Матеріали та методи. Вибірка складалася з юних футболісток віком до 14 років (n = 29, 13,06 ± 1,27 років, 47,8 ± 2,6 кг; 143,2 ± 3,4 см). До і після виконання двох тренувальних протоколів, спрямованих на визначення стану втоми (протокол визначення функціональної здатності при короткочасній втомі та RSA протокол — здатність до повторного спринту), техніку приземлення оцінювали за допомогою Landing Error Scoring System (LESS) — системи оцінки помилок при приземленні.

Результати. Система оцінювання LESS для показників стану здоров'я перед втомою і після виконання протоколу визначення функціональної здатності при короткочасній втомі показала значення 6,78 ± 0,81 і 8,74 ± 0,77 відповідно ($p > 0,001$, ES: 1,39). Результат LESS для стану після проведення RSA протоколу становив 8,52 ± 0,87; цей показник був статистично значуще вищим, ніж перед станом втоми ($p > 0,001$, ES: 1,24).

Висновки. Виконання інтенсивних фізичних вправ, як нервово-м'язових, так і метаболічних, впливає на техніку приземлення юних футболісток.

Ключові слова: приземлення, юні футболістки, профілактика травматизму, втома.

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Determining the Quality of Measuring the Level of Lower Extremity Joint Movement in Inclusive Physical Education Using Electronic IT Resources

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Abstract

Objectives. The study aimed to investigate the quality characteristics of the tool developed based on electronic IT resources for measuring the level of movements in the joints of the lower limbs of students with disabilities caused by injuries.

Material and methods. The experimental study involved 32 first-year students who had sustained lower limb injuries as a result of the war and were in remission. The methods used included analysis, synthesis, systematization, generalization, technical modeling, pedagogical experiments, and mathematical statistics.

Results. A means of measuring movements in the joints of the lower limbs has been developed using electronic IT resources. The basis of the tool is a measuring line consisting of a printed circuit board on which is placed a design of capacitive sensors, a switching line, and a signal converter that measures the signal received by the sensors. The measurement results are transmitted to the controller and then to the PC via an interface implemented based on Bluetooth wireless technology. To implement the measuring tool, a controller is used, which has a board built on the synthesis of the Arduino electronic hardware platform and the Raspberry Pi minicomputer. The test results are displayed on the PC monitor screen. The determination of the qualitative characteristics of the test, in the case of recording the results of a tool developed on the basis of electronic IT resources for measuring the level of movements in the joints of the lower limbs of students with disabilities, established that the level of reliability of the test is above 0.90 ("excellent") validity – from 0.6 ("high"). Empirical data collected directly from the experiment have a low level of reliability: qualitative indicators of reliability in the range are below 0.70 ("may have limited applicability"), validity – < 0.3 ("low validity").

Conclusions. Developed based on electronic IT resources, the tool for measuring the level of movements in the joints of the lower limbs of students with disabilities due to limb injuries has significant advantages, such as the availability of functions, ease of use and efficiency. Ensuring high efficiency and objectivity of control contributes to performing control operations in real-time. By using assessment tools with a high level of reliability and validity, we ensure the detection of reliable changes in the state of the joints of the lower limbs of students with disabilities, thus eliminating the influence of errors in making managerial decisions in the planning process of their PE.

Keywords: students with disabilities, physical education, testing, inclusion, control, quality.

Introduction

As a result of the full-scale war and massive missile attacks that Russia has been waging on the territory of Ukraine for more than two years in a row, the tendency to increase the number of students with disabilities in higher education institutions continues. At the moment, the first place among such a contingent of students are students who received a disability due to traumatic damage to their limbs. In particular, Ukrainian civilians receive such injuries as a result of shelling and bombing, and during hostilities, an extremely relevant mechanism of limb injuries today is an explosive injury.

Today requires a new approach to adapting and restoring the health status of students with disabilities in the environment of higher education – modern technological solutions and an integrated approach (Blavt, Bodnar, Mykhalskyi, Gurtova, & Tsovkh, 2023). Solving this issue in the learning process takes place in the process of implementing inclusive physical education (PE).

Educating students with disabilities in institutions of higher education poses a number of challenges that require comprehensive solutions (Grenier, Patey, & Grenier-Burtis, 2022). The view of well-known authorities in this field is convincing (Kuntjoro, Soegiyanto, Setijono, & Suhiharto, 2022; Page, Anderson, & Charteris. 2021) that the indicator of modern quality education is innovative activity. Scientific investigations (Varga, & Révész, 2023; Blavt, Chaplinskyi, Prozar, Pityn, Helzhynska, Dmytruk, Hrebik, & Kovalchuk, 2023; Gupta, 2021) focus on the fact that, in accordance with the modern innovative progress, this involves the introduction of the latest achievements of technological development.

The problem of the quality of inclusive PE in connection with the constant increase of students with disabilities is in the epicenter of researchers' attention (Blavt, Iedynak, Pereverzieva, Holub, & Melnyk, 2023; Pellerin, Wilson, & Haegele, 2022). In this context, they talk about the quality of physical education (Pocock, & Miyahara, 2018), its control (Blavt, & Gurtova, 2023; Mykytyuk, Blavt, Hnatchuk, Stechkevych, & Helzhynska, 2022), verification (Rekaa, Hanisch, & Ytterhus, 2019), evaluation (Lieberman, & Houston-Wilson, 2017).

Certain works, which are focused on the issues of restoring the health of students with disabilities, see the solution to this issue in the use of the basics of inclusive pedagogy, innovative practices of inclusive PE and integration into this process, modern information and communication (IT) resources (Gogoi, 2019; Qi, & Ha, 2012; Blavt, Chaplinskyi, Prozar, Pityn, Helzhynska, Dmytruk, Hrebik, & Kovalchuk, 2023). On the other hand, according to (Beazell, Grindstaff, Sauer, Magrum, MIngersoll, & Hertel, 2012; Cimbiz, & Bayazit, 2004; Doherty, Delahunt, Caulfield, Hertel, Ryan, & Bleakley, 2014), the complex recovery needs of traumatic limb injury include ongoing assessment of the process of strengthening lost functions.

In view of the continuation of the armed confrontation with the aggressor and the prevalence of injuries associated with the consequences of military actions, the issue of restoring lost functions due to limb injuries in students with disabilities during their studies in higher education institutions is now gaining special importance.

Purpose of the research in the study of qualitative characteristics of the quality of the tool developed on the basis of electronic IT resources for measuring the level of movements in the joints of the lower limbs of students with disabilities due to injuries.

Materials and Methods

Study Participants

32 students with disabilities in the 1st year of study from Lviv Polytechnic National University, Kamianets-Podilskyi Ivan Ohiienko National University and Lutsk National Technical University took part in the experimental study. The studied sample for the implementation of the research plan was formed randomly without taking into account the gender factor. It included students who received injuries to their lower limbs as a result of the war and were in remission.

Students with disabilities involved in the study underwent a thorough medical examination and received a doctor's permission to participate in the experiment. Positive dynamics of the functional state were established in all study participants. Consent to participate in the experiment was obtained from all students with disabilities who made up the studied sample.

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 Methods

The research has a multi-method applied nature and is implemented at the theoretical and empirical level. The procedure for solving the research task involved the use of a systematic approach in the search for research methods as an integrated set of tools for its implementation (Ivashchenko, 2020).

General scientific methods of theoretical research are used: analysis, synthesis, abstraction, generalization. At the empirical level, the method of technical modeling (to create a means of control) and a pedagogical experiment was used.

During the pedagogical experiment, testing was carried out. The implementation of the research plan involved the selection of the appropriate purpose of the test exercise. The Weight Bearing Lunge Test was chosen by us due to its ease of execution and the possibility of repeated reproduction.

According to the information (Weight-bearing lunge test), this test is considered simple for measuring the range of dorsiflexion of the ankle joint under load, which is a key component of gait in healthy ankles and in diseases of the musculoskeletal system (is a simple method of measuring weight bearing ankle dorsiflexion range, a key component of gait, in healthy ankles and a range of musculoskeletal conditions)

The Weight-bearing lunge test (WBLT) is used to assess the dorsiflexion range of movement at the ankle joint. (Powden, Hoch, Hoch, 2015; Konor, Morton, Eckerson, Grindstaff, 2012)

Test Procedure

This test needs to be done against a wall. A standard tape measure (cm) is necessary. Students are asked to place their feet in such a way that an imaginary line drawn through the heel and big toe is aligned on the tape measure on the floor. Furthermore, a vertical line is drawn on the wall in line with the tape measure. Students are instructed to lunge forward until their knee touches the wall (vertical line). The heel is required to remain in contact with the floor at all times. The foot is moved away from the wall to the point where the knee can only make slight contact with the wall, while the heel remains in contact with the floor. This puts the ankle

joint in maximal dorsiflexion. The leg not being tested can rest on the floor and students are allowed to hold onto the wall for support. The maximum distance from the wall to the tip of the big toe is recorded. The distance is measured in centimeters (cm) with each centimeter corresponding to approximately 3.6° of ankle dorsiflexion (Weight-bearing lunge test).

Research Organization

The research was carried out within the course of inclusive PE for three months. The testing was carried out at the beginning of the month, the students of the studied sample performed the tests three times with each limb. In the presence of a pain syndrome, students were not allowed to take the test. Clear instructions for performing the test exercise were provided, after which there was an opportunity to try.

The experimental factor consisted of fixing the results of the test exercise since the degree of reliability can be affected by the subjective approach when evaluating the test results. In one case, the results were recorded by the teacher, in the other - with the use of a tool developed for measurement, the evaluation of the test was carried out without subjective judgment. It should be noted that the test results were recorded simultaneously by two alternative measurement methods during each test. It is taken into account that the presumption of obtaining data may be imperfect in the presence of influence. To form research conclusions, the average value of the generated data was used.

Statistical Analysis

Determining the quality characteristics of the test involves establishing the numerical values of reliability and validity. As the technical properties of the test, the quality characteristics indicate the quality and usefulness of the test. The determination of these parameters allows establishing the compliance of the test with formal criteria that determine its quality and suitability for use in practice with a certain contingent of subjects.

The study takes into account that the reliability of a test limits its validity, and therefore a test that is not reliable cannot be valid. Quality control of the tests was carried out by establishing the strength of the correlation, which is determined by the value of the correlation coefficient. The coefficient is expressed as a Pearson correlation, a measure of linear correlation between two sets of data that ranges from +1.00 to -1.00 (Turney, 2022). The measure of correlation has become the basis of judgments about the validity of the test: a correlation value of less than 0.2 or 0.3 provides empirical evidence that the test is unsuitable for use in practical work (Eisinga, Te Grotenhuis, Pelzer, 2012).

All statistical analyses were performed using SPSS Version 22.0 (IBM Corporation).

Results

Determining the flexibility of the ankle joint in the process of recovery after a traumatic injury to a limb is considered an opportunity to control the process of recovery after a traumatic injury to a limb, which is accompanied by limitation of mobility and range of motion, possibly caused by cicatricial tightening of the skin, tendons, pain reflex, pathological changes in the muscular system (as excessive foot pronation or plantar fascia), etc. (Dai, Herman, Liu, Garrett, & Yu, 2012).

In our study, we were guided by the information that a decrease in the range of motion of dorsiflexion of the ankle joint has been identified as a risk factor for lower limb injuries during physical activity (Wahlstedt, & Rasmussen-Barr, 2014). According to available data (Hall, & Docherty, 2017), a total lunge distance of less than 10 cm or a side-to-side discrepancy of more than 2 cm is associated with a risk of lower extremity injuries such as sprained ankle ligaments or possible tibial fracture. In addition, it has been proven that the efficiency of the walking function is provided by the appropriate range of motion in the ankle dorsiflexion (O'Shea, & Grafton, 2013).

As noted, the absence of adequate amplitude in the ankle indicates the presence of pathological changes (Lin, Moseley, Robert, Herbert, & Refshauge, 2009). Therefore, permanent control in the process of restoring the functions of the lower limbs is the basis of this process.

Our scientific search was conditioned by the fact that, according to empirical sources, ankle dorsiflexion testing is traditionally performed using a goniometer (Cosby, & Hertel, 2011) or an inclinometer (Beazell, Grindstaff, Sauer, Magrum, Ingersoll, & Hertel, 2012) or a tape measure (Matthew, Hoch & McKeon, 2011). However, none of these methods ensures the elimination of the influence of the human factor. In addition, fixing the result using such means is technically difficult.

The actual material collected and analyzed proved the possibility of developing a means of measuring movements in the joints of the lower limbs based on electronic IT resources. The design solution of the tool involves the use of a measuring line, which is built using the concept of capacitive sensors (Mykytyuk, Kremer, Ivakh, Diskovskyi, & Khomyak, 2021). The basis of the capacitive measuring line is a printed circuit board that integrates capacitive sensors, a switching line, and a signal converter (Mykytyuk, Barylo, Kremer, Kachurak, & Shymchyshyn, 2024).

The signal is measured by a signal converter, and the measurement results are transferred to the controller by an interface based on wireless Bluetooth technology. The signal converter provides further signal conversion and processing of digital data and RF radio frequency transmission to a personal computer (PC). Processing of the received data and their visualization is carried out by the corresponding software for the implementation of the measurement, which is developed in the Arduino IDE environment.

To implement the measuring tool, a controller is used, which has a board built on the synthesis of the Arduino electronic hardware platform and the Raspberry Pi minicomputer. The controller in the developed control tool performs the following functions: it automatically manages the control process, in case of non-compliance with the requirements, signals and stops this process, receives information recorded by sensors, processes it, and transmits it to a PC.

All information is displayed on the PC monitor in digital and graphic form. The PC implements recording and storage of control data and statistical analysis of data that are available to the user as needed.

Table 1. Quality level of the Weight Bearing Lunge Test for students with disabilities due to injuries (n=32)*

rtt	T	R	T	R	T	R	T	R
reliability	0.616	0.908	0.640	0.901	0.589	0.897	0.611	0.917
validity	0.201	0.603	0.207	0.597	0.176	0.612	0.233	0.591

* Note: T – recorded by the teacher, R – recorded using a measuring ruler

The developed measuring tool for the implementation of the Weight-Bearing Lunge Test is used as follows. A capacitive measuring ruler is placed on the wall and the floor. The student takes the starting position for the test exercise and moves his foot on the ruler. Next, the student lunges forward until his knee touches the wall, where a capacitive measuring ruler is also placed along the vertical line. At the moment of touching the ruler placed vertically on the wall with the knee, the maximum distance from the wall to the tip of the big toe is fixed with the ruler placed horizontally.

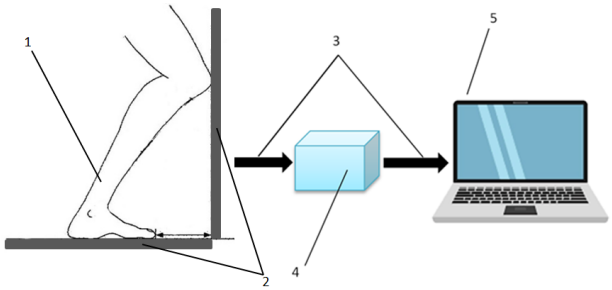

Fig. 1. Scheme of the developed on the basis of electronic IT resources for measuring the level of movements in the joints of the lower limbs (1 – student, 2 – capacitive measuring ruler with printed circuit board, 3 – infrared communication lines, 4 – controller, 5 – PC)

Further, our study consisted in presenting the test results, which were recorded using a measuring ruler and directly by the teacher (Table 1).

The conducted research established that the use of different means of fixing the test results leads to a significant difference in the test results. Taking into account the fact that the collection of empirical data of the experiment directly depends on the human factor, in particular on professional experience, the results obtained in this way have a low level of quality: qualitative indicators of reliability within the limits – below 0.70 ("may have limited applicability"), validity – < 0.3 ("low validity"). Therefore, we have grounds for the conclusion that such control cannot be an objective basis for planning the educational process.

By determining the quality characteristics of the test, in the case of fixing the results of a tool developed based on electronic IT resources for measuring the level of movements in the joints of the lower limbs of students with disabilities due to injuries of the limbs, it was established that the level of reliability of the test is above 0.90, validity – from 0.6. Such numerical values of reliability correspond, according to the rating scales, to the level of "excellent", validity – to "low validity of the test".

Discussion

In Ukraine, persons with disabilities have access to higher education and the conditions for obtaining it. The conducted study expands the information (Blavt, Bodnar, Mykhalskyi, Gurtova, & Tsovkh, 2023; Doherty, Delahunt, Caulfield, Hertel, Ryan, & Bleakley, 2014) on solving the problem of normalization of the physical condition of students with disabilities who were injured as a result of war, by eliminating existing health problems during training.

Our scientific intelligence is conditioned by the fact that the challenges that have arisen before the education system of Ukraine are connected with the long-term conduct of hostilities in connection with the military aggression of the Russian Federation. Our study extends the body of research on inclusive PE in educational settings (Grenier, Patey, & Grenier-Burtis, 2022; Pellerin, Wilson, & Haegele, 2022) as a means of restoring function lost due to injury. Inclusion in regular PE classes of students with disabilities requires adaptation of strategies for this process and its assessment to their individual needs (Pocock & Miyahara, 2018; Blavt & Gurtova, 2023).

We support scientific approaches (Page, Anderson, & Charteris. 2021; Gupta, 2021; Blavt, Chaplinskyi, Prozar, Pityn, Helzhynska, Dmytruk, Hrebik, & Kovalchuk, 2023) that meeting today's demands in the field of inclusive PE requires innovative solutions with using modern technological resources.

The work presents a development that meets the challenges of modernity in the implementation of monitoring procedures since when restoring functions are lost as a result of an injury when it is extremely important to start recovery quickly, monitoring must be informative and fast. In our study, we were guided by the fact that ankle dorsiflexion range of motion is often emphasized (Powden, Hoch, & Hoch, 2015; Beynon, Le May, & Theroux, 2022) in rehabilitation of lower extremity injuries. To date, there is a certain list of scientific studies where The Weight Bearing Lunge Test has been used to test completely healthy individuals (Konor, Morton, Eckerson, & Grindstaff, 2012; O'Shea, & Grafton, 2013) and athletes (Cady, De Ste Croix, & Deighan, 2021) and as a universal assessment test (Howe, Bampouras, North, & Waldron, 2020).

In our study, the sample was formed from persons who have disabilities due to injuries of the lower limbs, and therefore, it expands the range of previous studies in a certain direction. The direction of the research was justified by the fact that the validity of the test is established in relation to specific reference groups (target group) of persons with certain common characteristics.

Conclusions

Russian aggression against Ukraine has caused a serious increase in the number of students with disabilities who have been injured as a result of the war. Strategic orientations for the recovery of the health status of students with disabilities, who received injuries of the lower extremities as a result of

the war, are considered in the context of the possibilities of inclusive PE and the integration of the latest technologies into the control of this process.

Developed based on electronic IT resources, the tool for measuring the level of movements in the joints of the lower limbs of students with disabilities due to limb injuries has significant advantages, such as the availability of functions, ease of use, and efficiency. Ensuring high efficiency and objectivity of control performs control operations in real-time. Moreover, this tool is non-invasive, inexpensive, and does not emit radiation.

According to the results of the analysis of the qualitative characteristics of the qualitative characteristics of the means of measuring the level of movements in the joints of the lower limbs of students with disabilities developed based on electronic IT resources, it was established that the numerical values of the reliability and validity indicators reached a high level according to the rating scales. Using evaluation tools with a high level of quality, we ensure the objectivity of control and elimination of the influence of errors in making management decisions in the planning of the PE process.

Using a test to measure the level of movement in the joints of the lower limbs of students with disabilities, when the results are recorded by the teacher, is not justified due to large measurement errors. A low level of reliability is not the basis for informed decisions and the understanding that the test results are not an artifact of the instrument.

Conflicts of interest

No conflicts of interest exist.

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Визначення добротності розробленого на основі ІТ-ресурсів засобу вимірювання рівня рухів у суглобах нижніх кінцівок у інклюзивному фізичному вихованні

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Мета дослідження полягала у дослідженні якісних характеристик добротності розробленого на основі електронних ІТ-ресурсів засобу вимірювання рівня рухів у суглобах нижніх кінцівок здобувачів вищої освіти з інвалідністю внаслідок травм.

Матеріал та методи. У дослідженні прийняли участь 32 здобувачів вищої освіти І курсу навчання, які отримали травми нижніх кінцівок внаслідок війни і знаходяться у стані ремісії. Використано методи: аналізу, синтезу, систематизації, узагальнення, технічного моделювання, педагогічного експерименту та математичної статистики.

Результати. Розроблено на основі електронних ІТ-ресурсів засіб вимірювання рухів у суглобах нижніх кінцівок. Основою засобу є вимірювальна лінійка, яка складається з друкованої плати, на якій розмішено конструкція з ємнісних сенсорів, лінії комутації та сигнального перетворювача, який вимірює сигнал, отриманий сенсорами. Передачу результатів вимірювання на контролер, а далі на ПК, – інтерфейсом, реалізовано на основі безпровідної Bluetooth технології. Для реалізації засобу вимірювання, використано контролер, який має плату, побудовану на синтезі електронної апаратної платформи Arduino и мінікомп'ютера Raspberry Pi. Результати тестування представляються на екрані монітора ПК. Визначенням якісних характеристик добротності тесту, у разі фіксації результатів розробленим на основі електронних ІТ-ресурсів засобу вимірювання рівня рухів у суглобах нижніх кінцівок студентів з інвалідністю, встановлено, що рівень надійності тесту становить вище 0,90 («відмінна») валідності – від 0,6 («висока»). Емпіричні дані експерименту зібрані прямим способом володіють низьким рівнем добротності: якісні показники надійності у межах – нижче 0,70 («має обмежене застосування»), валідності – < 0,3 («низька валідність»).

Висновки. Розроблений на основі електронних ІТ-ресурсів засобу вимірювання рівня рухів у суглобах нижніх кінцівок студентів з інвалідністю внаслідок травм кінцівок володіє значним перевагами, як от доступність функцій, простота у використанні й ефективність. Забезпечуючи високу ефективність та об'єктивність контролю, здійснює виконання контролювальних операцій у режимі реального часу. Використовуючи інструменти оцінювання з високим рівнем добротності, забезпечуємо виявлення достовірно змін у стані суглобів нижніх кінцівок студентів з інвалідністю та усунення впливу помилок у прийнятті керівних рішень планування процесу їхнього ФВ.

Ключові слова: здобувачі вищої освіти з інвалідністю, фізичне виховання, тестування, інклюзія, контроль, добротність.

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Does Short-Term Speed Endurance Soccer Training Improve Physical Performance?

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Abstract

Objectives. This study is aimed at analyzing the impact of short-term Speed Endurance Soccer Training (SEST) training on the physical performance of young soccer players.

Materials and methods. The true experiment method was used in this study. The study population comprised a total of 122 individuals. Furthermore, by using random sampling techniques, a sample of 30 persons was selected with an average age of 15.2 ± 0.81 years, height 168.1 ± 4.82 cm, weight 57.85 ± 11.93 kg, and BMI 20.34 ± 3.37. Physical performance instruments included the Running Based Anaerobic Sprint Test (RAST), Yo-Yo intermittent test level 1, 20-meter sprint, and standing broad jump test. The study used the paired t-test to evaluate the effect of each group and the independent samples t-test to compare the improvement in the experimental (SEST) and control groups. Statistical significance was set at $p < 0.05$.

Results. The paired t-test showed significant differences between the pretest and post-test in the SEST group in anaerobic ($p = 0.000$, $\Delta\% = 8.4$), aerobic ($p = 0.000$, $\Delta\% = 7.48$), and speed ($p = 0.000$, $\Delta\% = 3.39$) capacities. Meanwhile, there were no considerable differences in the variables for the control group. According to the independent t-test results, a significant difference in effect between the SEST group and the CTRL group was revealed. The SEST group demonstrated marked differences in anaerobic, aerobic and speed variables with a p-value = 0.000.

Conclusions. The study reveals that short-term Speed Endurance Soccer Training contributes to enhancing the physical performance of soccer players. However, caution should be exercised regarding the potential risk of hamstring injury in individuals with unprepared muscles.

Keywords: soccer, speed endurance soccer training, physical performance.

Introduction

Soccer has high physical demands (Mendez-Villanueva et al., 2013; Rebelo et al., 2014). Attacking, transitioning and defending are three important soccer moments requiring high physical quality. Excellent physical quality is required to make a positive transition from defending to attacking well, and vice versa with negative transitions.

Often, training models that are partial or not holistic can become an obstacle in the player development process. Physical training is often carried out separately with technical and tactical components, such as plyometric training by Kusuma et al. (2023), Maciejczyk et al. (2021), Padrón-Cabo et al. (2021), High-Intensity Interval Training (HIIT) by Arslan et al. (2021); D'Isanto et al. (2022), Speed Endurance Training (SET) by Iaia et al. (2015), Ikhsan et al. (2023), Mohr & Krustrup (2016) and others. Even though the results of this research have a positive impact on the physical performance of soccer players, if we look at the implementation of the training, it is still separated between

physical and other components, resulting in a lack of contact with the ball on the players, so it is possible to have an impact on the players' performance on the field. Apart from that, according to Izquierdo et al. (2023), coaches must develop training programs that suit the needs of the competition.

A holistic training model is needed so that the physical training carried out meets the competition's needs. In line with several studies that have been conducted, which found the theory that the integration of non-specific training together with soccer routines will maintain the level of technical and physical skills, according to Clemente et al. (2022), as well as player enjoyment Formenti et al. (2021), Ridwan et al. (2022).

One solution that can be adopted to overcome the problems faced in developing physical, technical, tactical and mental components is to apply the Speed Endurance Soccer Training (SEST) model. This exercise adopts the Long Interval Speed Endurance Training Maintenance (SET-M) theory with an intensity of 50-80%, 15-90 seconds duration, ratio 1:1-1:3, and repetitions 6-12 (Hostrup & Bangsbo, 2023). This approach combines elements of high-intensity speed training with tactical elements in matches, in line with the research of M. Oliva-Lozano et al. (2023), who found that repeated sprinting abilities are very much needed in soccer. The training intensity used in this exercise is classified as high intensity using anaerobic and aerobic energy systems. These drills are designed to improve a player's physical fitness, technical skills, tactical understanding and mental toughness.

This research was conducted to analyze the SEST training model on the physical abilities of football players. SEST adopts a SET and tactical approach in the game of soccer. Apart from that, this research aims to develop a holistic training method. Conducting SEST research is essential because it can provide scientific evidence about this exercise's effectiveness in improving soccer players' performance and physical fitness. This is very important because it can help soccer coaches design effective and efficient training programs and improve the overall health and performance of soccer players.

Materials and Methods

Study Participants

A total of 122 male soccer players were the population in this study, and 30 players were taken as samples. Samples were taken using a random sampling technique. Sample characteristics: age 15.2 ± 0.81 years, height 168.1 ± 4.82 cm, weight 57.63 ± 11.93 kg, and BMI 20.26 ± 3.37. Of the 30 samples, 15 were in the control group (CTRL), and 15 were in the treatment group (SEST).

Study Organization

The method used in this research is an experimental method with a two-group pretest and posttest design, where the sample is divided into a control group and an experimental group. Sample selection used random sampling techniques. This research uses Polar Verity Sense to monitor heart rate to keep it at a high intensity. Physical performance test instruments use the RAST Test, Yoyo Intermittent Recovery Test level 1, RAST Test, and Srint 20 meter test. This research was approved by the Health Research Ethics Committee Nahdlatul Ulama University of Surabaya (registration number 0276/EC/KEPK/UNUSA/2023 - Date of approval: July 12, 2023).

Procedure and Training Program

Both groups were given a pretest to determine their initial physical performance. Next, the treatment group was given SEST training for four weeks with a frequency of three times a week, while the control group was given training as usual with the same duration and frequency as the treatment group. Before the treatment, the 15 sample people were divided into three groups, consisting of 3 attacking players and two defensive players. The SEST implementation procedure consists of several steps. First, group one played 3v2 in the penalty box area. During training, both teams ran back and forth for four repetitions, both on attack and defence, in one set. Each team player is given five balls to score each time a team attacks or defends. After the first group completes five balls or one set, proceed to the second group. Each group's total number of repetitions was six, with three sets attacking from the right side and three from the left side of the field. To maintain a high training intensity, a training ratio of 1:3 is used, which means one work section followed by three rest sections.

The training program implemented in this research is in Table 1. In one set, the estimated distance covered by each player is around 120 meters, with an average travel time of around 88 seconds, followed by a rest of 234 seconds before the next set begins. It is estimated that the total distance travelled by players in one training session is 720 meters.

Table 1. Training Program

Set	Speed Endurance		Tactical Component		Attack Side	Intensity
	Distance (m)	Time (s)	Action	Time (s)		
1 Set	20	3	Early Cross	10	Right/Left	80-90 % HrMax
	20	3	Penetration Cross	10	Right/Left	
	20	3	Early Cross	10	Right/Left	
	20	3	Penetration Cross	10	Right/Left	
	20	3	Early Cross	10	Right/Left	
	20	3	Penetration Cross	10	Right/Left	
Estimated distance 120 meters Intervals 1:3, with 78 seconds of work and 234 seconds of rest						< 70 % HrMax

Statistical Analysis

Data are presented in the form of mean and standard deviation. The normality test uses the Shapiro-Wilk test, and the homogeneity test uses the Levene test. The percentage change (Δ%) between the results before and after the training period. The paired t-test was used to see the effect of each group, and the independent sample t-test was used to compare the improvement in the experimental and control groups. Statistical significance was set at $p < 0.05$. Effect sizes (ES) were calculated using Cohen's ES to measure the magnitude of differences between groups. ES above 0.8 is large, 0.8-0.5 is medium, 0.5-0.2 is small, and less than 0.2 is insignificant (Cohen, 2013).

Results

Average data for the two groups which took part in Soccer Endurance Speed Training (SEST) and the control group (CTRL) are shown in Table 2. Participants' age, height, weight, and Body Mass Index (BMI) were measured for both groups.

Table 2. Characteristic of group

Group	Age (year)	Height (cm)	Body Mass (kg)	BMI
SEST	15.27±0.8	168.07±5.61	57.53±12.15	20.21±3.30
CTRL	15.13±0.83	168.13±4.09	57.73±12.12	20.30±3.57

Data are presented as mean±SD

The Shapiro-Wilk normality test showed that all variables in the SEST and CTRL groups had a normal distribution with a significance value of Sig>0.05. The same thing was also found in the homogeneity test using the Levene test, showing a significance result of > 0.05.

The results of the pretest and posttest physical performance tests are in Table 3. The variables observed include anaerobic power (watts), aerobic power (ml/kg/min), and speed (seconds). Data were divided into two groups: the group that underwent SpeedEndurance Soccer Training (SEST) and the control group (CTRL). Pretest and posttest results and percentage changes (Δ%) are presented for each variable in both groups. In addition, significance (P) and effect size (ES) values were also reported for each variable in the two groups.

The difference in effect was significant between the SEST group and the CTRL group. Anaerobic, aerobic, and speed variables in the SEST group showed significant differences with p-value = 0.000. More complete data is shown in Table 4.

Discussion

The research results show that SEST has a significant influence on improving the physical performance of soccer players. SEST is a combination of speed endurance training and soccer tactics training. These findings are in line with previous research conducted by Sports Arslan et al. (2020), which compared running-based high-intensity interval training vs. small-sided game training programs with the results of small-sided game training become more effective training to improve technical abilities and dexterity with a greater level of enjoyment, while running-based high-intensity interval training is more suitable for speed-based conditions in soccer players young.

Previous research found that high-intensity interval training can improve soccer players' aerobic and anaerobic abilities (Arazi et al., 2017; Fang et al., 2021). In practice, high-intensity interval training induces more excellent glycolytic activity in a short time, resulting in the production of lactic acid, and this activity beneficially contributes to producing higher levels of ATP (Stöggl & Björklund, 2017). In line with the principles of the lactic anaerobic energy system,

Table 3. Results of pretest and posttest physical performance

Variable	Group	Pre	Post	Δ%	P	ES
Anaerobic Power (watt)	SEST	386.63 ± 106.50	411.22 ± 113.09	6.36	0.000*	1.79
	CTRL	389.41 ± 105.87	388.53 ± 106.78	-0.22	0.469	0.19
Aerobic (ml/kg/min)	SEST	41.33 ± 3.01	44.42 ± 3.44	7.48	0.000*	2.61
	CTRL	41.30 ± 2.90	41.40 ± 2.71	0.22	0.464	0.19
Speed (second)	SEST	4.03 ± 0.25	3.89 ± 0.19	3.39	0.000*	1.27
	CTRL	4.04 ± 0.26	4.03 ± 0.27	0.05	0.866	0.04

Data are presented as mean±SD; Δ (%): percentage of change between pre and post-training performance; p: level of significance; ES: effect size; * Significant difference, $p < 0.05$.

Table 4. Comparison of physical performance variables in both groups

Variable	SEST	CTRL	Δ%	P	ES
Anaerobic Power (watt)	24.59 ± 13.69	-0.87 ± 4.55	-103.56	0.000*	2.5
Aerobic (ml/kg/min)	3.09 ± 1.18	0.09 ± 0.47	97.07	0.000*	3.33
Speed (second)	0.14 ± 0.011	0.00 ± 0.05	98.62	0.000*	1.7

Data are presented as mean±SD; Δ (%): percentage of change between group SEST and CTRL group; p: level of significance; ES: effect size; * Significant difference, $p < 0.05$.

SEST work applies a 1:3 interval with a high-intensity work time of 50 seconds and rest for 150 seconds. Other research has proven that 1:5 and 1:1 intervals significantly increase endurance tested using a yoyo intermittent recovery test level 1 (Diker et al., 2023).

The implementation of SEST covers a sprint distance of 160 meters multiplied by 6 sets, where this model has the Long Sprint Training category. In previous research, Rey et al. (2024) reported that Short Sprint Training (SST) and Long Sprint Training (LST) were effective in improving performance measures specific to soccer. However, LST had a better percentage of improvement, with analysis showing significant improvement in 5 m, 10 m, 20 m, 30 m and 40 m sprint. This strengthens the SEST findings, which are included in the ESG category.

Apart from that, SEST requires the work of the hamstrings and quadriceps to perform and stabilize sprint movements, pass the ball, and control the ball towards the goal. This is in line with a systematic review study conducted by Baroni et al. (2020), which concluded that the quadriceps play an essential role in jumping and kicking a ball, while the hamstrings are known to control running activities and stabilize the knee joint when turning or making a tackle. This aligns with research by Fransson et al. (2018), which found that high-intensity interval training with speed resistance increased muscle oxidative capacity and sports performance as well as muscle ion transporters and muscle antioxidant capacity in soccer players.

Previous research conducted by Nayıroğlu et al. (2022) comparing the effects of running-based small-sided games (SSG) and high-intensity interval training (HIIT) on body composition and physical fitness in youth women's soccer found HIIT SSG and HIIT were equally effective for improving vertical and horizontal jumping ability, change of direction, and aerobic capacity status, these findings are in line with this research, but this research has a slightly different model, namely combining a high-intensity training model with football tactics. In contrast, the previous research was carried out separately. Apart from that, this research has a positive effect on anaerobic capacity. Previous research combined tactical and physical training with almost the same characteristics (Arslan et al., 2021). Previous research shows that the combination of SSG and HIIT is efficacious in improving young soccer players' physical and technical performance. These findings align with this research, but what differentiates this research is how the training is carried out, whereas previous research was carried out alternately. On the other hand, this research was carried out jointly or holistically.

An interesting limitation of SEST is that hamstring injury is possible in some samples. This is possible because the hamstring muscles are not ready before SEST treatment. This is in line with research by Moreno-Perez et al. (2023), which indicates that short periods of unusually long running can increase the risk of hamstring injury in soccer players. With these findings, it can be concluded that SEST training is unsuitable for players with weak hamstrings or players who are not used to doing repetitive sprints.

Conclusions

Overall, the research results show that SEST, a combination of speed endurance and soccer tactics training, significantly influences players' physical performance. However, remember that this exercise can potentially cause hamstring injuries in some individuals, especially if the hamstring muscles are not ready. Therefore, when implementing SEST, players' physical condition and habits must be considered to minimize the risk of injury.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Чи покращують короткотривалі тренування з футболу на розвиток швидкісної витривалості фізичну продуктивність?

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 4 табл., 27 джерел.

Мета дослідження. Це дослідження спрямоване на аналіз впливу короткотривалих футбольних тренувань з розвитку швидкісної витривалості (SEST — Speed Endurance Soccer Training) на фізичну продуктивність юних футболістів.

Матеріали та методи. У дослідженні застосовано метод істинного експерименту. Загальна кількість досліджуваних становила 122 особи. Крім того, методом рандомізації була відібрана вибірка в кількості 30 осіб із середнім віком 15,2 ± 0,81 року, зростом 168,1 ± 4,82 см, вагою 57,85 ± 11,93 кг та ІМТ 20,34 ± 3,37. Засоби оцінки фізичної продуктивності включали анаеробний тест на основі спринтерського бігу (RAST тест), Yo-Yo тест на витривалість 1-го рівня з перервами на відновлення між тренуванням, спринтерський біг на 20 метрів та тест зі стрибків у довжину з місця. У дослідженні застосовано парний t-критерій для оцінки впливу кожної групи та t-критерій для незалежних вибірок з метою порівняння покращення показників в експериментальній (SEST) та контрольній групах. Статистична значущість була встановлена на рівні $p < 0,05$.

Результати. За результатами дослідження із застосуванням парного t-критерію встановлено наявність значних відмінностей між показниками до і після проведення тесту в групі досліджуваних SEST в анаеробній ($p = 0.000$, $\Delta\% = 8,4$), аеробній ($p = 0.000$, $\Delta\% = 7,48$) і швидкісній ($p = 0.000$, $\Delta\% = 3,39$) здатностях. Натомість у контрольній групі не спостерігалося суттєвих відмінностей у досліджуваних змінних. Згідно з результатами t-критерію для незалежних вибірок, було виявлено суттєву різницю у показниках ефективності між групою SEST та контрольною групою. Група SEST продемонструвала істотні відмінності в анаеробних, аеробних і швидкісних параметрах з p-значенням = 0,000.

Висновки. Дослідження показує, що короткотривалі тренування з футболу для розвитку швидкісної витривалості сприяють покращенню показників фізичної продуктивності футболістів. Однак слід бути обережними через потенційний ризик травмування підколінного сухожилля у осіб з недостатньо розвиненими м'язами.

Ключові слова: футбол, тренування з футболу на розвиток швидкісної витривалості, фізична продуктивність.

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Analyzing the Perception of the Impact of Sports Practice on Students in School Settings

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Abstract

Objectives. The importance of physical activity is often underestimated, particularly by students, although there is some scientific evidence to support this. There is a lack of data on students' perceptions of sports practice, focusing on the aspect of well-being and the positive benefits of the latter, including in the school environment. The objective is to quantify the impact of sports practice on the well-being of secondary school students in the school setting.

Materials and methods. The sample taken consists of 25 students belonging to the first grades of the State Industrial Technical Institute "G. Cardano" in PAVIA. A questionnaire consisting of 16 questions was developed in order to investigate the relationship between well-being and physical activity among the students. Then, the responses to the questionnaire questions were analyzed, applying chi-squared test analysis to understand any significance among the qualitative variables.

Results. It was found that for the respondents, the relationship with sports is 16% indifferent, 4% not positive and 80% favorable. A first significant relationship was analyzed, between the amount in terms of frequency of sports activity and the students' feelings in the classroom while practicing ($p = 0.001$); and a second significant relationship was found between the amount in terms of frequency of sports activity and the students' feelings during the exercises ($p = 0.003$).

Conclusions. The main conclusion that can be drawn from this study is that sports activity has a positive impact on students' school life, influencing their physical and emotional well-being, enhancing a sense of inclusion and empowerment, and increasing motivation to achieve personal goals.

Keywords: school, wellness, sports, questionnaire, physical activity.

Introduction

In the fast-paced and increasingly competitive environment of modern life, the importance of sports in the school setting emerges as a crucial element in the overall well-being of students (Raiola, 2020). In scientific literature, there is evidence of the effectiveness of sports in developing not only skills and abilities, but also skills applicable to daily life (Raiola, 2019). Sport is not only a form of physical activity, but a powerful educational tool that contributes significantly to the formation of balanced and resilient individuals (D'Elia & D'Isanto, 2021). Sport represents a distinctive educational method that contributes to the formation of people with the ability to face challenges with determination (Ratey, 2008). Playing sports not only promotes physical health, but also plays an instrumental role in stress management and enhancing cognitive abilities (Hristovski et al, 2012). In addition, it can be regarded as a beneficial component for the brain, providing prevention against brain diseases (Raiola, 2017). Students who engage in sports develop better concentration, learning, and memory, which are key aspects for meeting academic challenges more effectively (D'Elia, 2019b). In addition, sports act as a laboratory for the growth of social and emotional skills. Practice in team sports teaches the value of teamwork, leadership, and managing emotions in high-pressure situations (Altavilla et al, 2018). Active participation in sports provides fertile ground for the development of social skills, including teamwork, leadership, and emotion management (Bailey, 2010). Such skills not only reflect positively in school dynamics, but also become an asset for success in adult life (Invernizzi et al, 2022). The

school environment, therefore, should not only be a place of learning, but also a fertile ground for the integral formation of individuals (Altavilla et al., 2015). Sport is presented as an effective means of promoting health, resilience, and socialization, thus creating a solid foundation for students' overall success, both in their academic careers and in everyday life (D'Elia, 2021). In addition, it has been shown how much sports practice can influence the cognitive aspect of students, both in terms of learning, school performance, and not to be underestimated, emotional development, understood as emotion management (Zourbanos et al., 2014). Regular practice of sports not only improves physical health, but also has a positive impact on cognitive functions, including attention and memory (Hillman et al., 2008). Sports can be an effective tool for promoting equity and inclusion within the school environment (D'Isanto, 2019). Through well-structured sports programs that are accessible to all students, socioeconomic, cultural, and gender barriers can be overcome, providing opportunities for everyone to participate in and benefit from the educational values of sports (Altavilla, 2019). Active participation in sports can help prevent school dropout by providing students with a positive and engaging experience outside the classroom (Vazou et al., 2019). Not to be underestimated, school sporting events can be an opportunity to actively involve families and the local community, creating closer ties between the school and the surrounding area. This involvement can contribute to greater social cohesion and broader support for student education and development (Abarca-Sos et al., 2013). Students involved in sports tend to have a greater motivation and sense of belonging to the school, reducing the risk of disengagement and poor academic performance (Baena-Extremera et al., 2013). This also enables the development of motivation in students, understood as achieving goals or simply in working to achieve certain goals (Parish & Treasure, 2003). Despite this, with the development of new technologies tending toward the entertainment of subjects at a young age, sports practice is not always considered of primary importance, taking into consideration more and more sedentary habits. The absence of the data of students' perceptions regarding sports practice was noted, focusing on the aspect of well-being and the positive benefits it brings even in the school environment. Often, the focus is mainly on the psychophysical value of sports in the social context, neglecting its relevance in the educational and school context.

Purpose of the research. The objective of the study is to quantify the impact that sports practice has on secondary school students in terms of well-being and positive influence, in the school setting.

Materials and Methods

Study Participants

The sample taken consists of 25 pupils belonging to the first classes of the State Industrial Technical Institute "G. Cardano" in PAVIA (PV). They are divided into 14 male and 11 female, with an age range of 14 to 16 years.

Study Organization

First, a questionnaire was developed to investigate the relationship between well-being and physical movement in students, containing 16 questions. The questionnaire is divided into three sections: the first contains profiling questions, the second contains questions about sports, and the third section contains group interaction questions. Analytically, the questions were designed to understand the

Table 1. Questionnaire to investigate the relationship between well-being and physical movement in students

	Questions:	Answer	Answer	Answer
1.	Gender of the interviewee:	Male	Female	
2.	Age of the interviewee:	Open answer		
3.	To which class the interviewee belongs?	Open answer		
4.	What sports activities does the person engage in?	Open answer		
5.	Sports activities are carried out:	Once/twice a week	Two/three times a week	None
6.	For the interviewee, sport is:	Fun	Well-being	Relationship
7.	What relationship does the respondent have with sports:	indifferent	Not positive	Favorable
8.	In the classroom, the student feels:	valued	included	hindered
9.	During sports, does the subject feel?	valued	included	hindered
10.	Does sports make you feel better?	YES	NO	Other (please specify)
11.	Does sport change your relationship with your teammates?	YES	NO	Other (please specify)
12.	With sports, do you feel motivated to achieve your goals?	YES	NO	Other (please specify)
13.	With sports do you interact with the group with interest and attention?	YES	NO	Other (please specify)
14.	Are you attentive and participatory during sports activities?	YES	NO	Other (please specify)
15.	Do you feel a sense of well-being after exercising?	YES	NO	Other (please specify)
16.	Is it possible to say that thanks to sports the class is satisfied?	YES	NO	Other (please specify)

basic characteristics of the respondents, to understand the respondent's orientations in relation to sport, group, and the topic of well-being and motivation. The questionnaire, of structured type and processed through Google Forms, was submitted aiming at the independent variables that cannot be influenced with respect to the individual person's behaviors and are already guided in the choice of a predefined response in relation to the Likert scale, the most used type among the predefined response possibilities. The questionnaire is represented in Table 1.

Statistical Analysis

Once the questionnaire was administered, a survey and analysis of the results was conducted, with the application of the ChiQuadro statistical tool to note any significant relationships between the qualitative variables. This was performed with the statistical analysis software "JASP".

Results

With the administration of the questionnaire, the following process was the processing of the latter Table 2. Shows the results of the responses to the questions.

Following the administration of the questionnaire, the data were analyzed. With question number 1 'Gender of the interviewee' it turns out 56% male and 44%. With question number 2 'Age of the interviewee,' it turns out that the age of the sample is between 14 and 16 years old, with 58% turned out to be 14 years old, 35% turned out to be 15 years old, and the remaining 4% turned out to be 16 years old. With the question 'What grade does the respondent belong to?' it turns out that 100% are attending the first grade of secondary school. Next with the question 'What sports activities does the subject engage in?' The following activities result with different percentages: Soccer for 24%, Volleyball for 16% %, Fitness for 40% (understood as activities carried out to physical well-being in the gymnasium), Tennis for 12% and No activity for 8%. With question 5 'Sports activities are carried out' it appears that 76% carry out the activity once/twice a week, 20% two/three times a week and the remaining 4% responded with 'other'. To the question 'For the interviewee, sport is' for 80% it is fun, for 16% it is well-being and for the remaining 4% it is relationship. With respect to question number 7 'What relationship does the respondent have with sports', it turns out that for the respondents the relationship with sports is for 16% Indifferent, for 4% not positive and for 80% Favorable. Next to question number 8 'In the classroom the student feels' it turns out that 20 % of

Table 2. Results of the questionnaire

	Questions					
1.	Gender of the interviewee:	Male	Female			
	Percentage	56,00%	44,00%			
	Frequency	14	11			
2.	Age of the interviewee:	14 years old	15 years old	16 years old		
	Percentage	15	9	1		
	Frequency	58,00%	35,00%	4,00%		
3.	What grade does the respondent belong to?	First	Second	Third		
	Percentage	25	0	0		
	Frequency	100%	0	0		
4.	What sports activities does the subject engage in?	Football	Volleyball	Fitness	Tennis	No activity
	Percentage	24,00%	16,00%	40,00%	12,00%	8,00%
	Frequency	6	4	10	3	2
5.	Sports activities are carried out:	the activity once/twice a week	two/three times a week	Not once		
	Percentage	76%	20%	4%		
	Frequency	19	5	1		
6.	For the interviewee, sport is:	fun	wellness	relantionship		
	Percentage	80%	16%	4%		
	Frequency	20	4	1		
7.	What relationship does the respondent have with sports:	Favoreble	Indifferent	not positive		
	Percentage	80%	16%	4%		
	Frequency	20	4	1		
8.	In the classroom the student feels:	hindered	enhanced	included		

	Questions			
	Percentage	20%	8%	72%
	Frequency	5	2	18
9.	During sports the subject feels?	hindered	enhanced	included
	Percentage	8%	32%	60%
	Frequency	2	8	15
10.	Does sports make you feel better?	YES	NO	
	Percentage	92%	8%	
	Frequency	23	2	
11.	Does sport change the relationship with peers?	YES	NO	
	Percentage	92%	8%	
	Frequency	23	2	
12.	With sports, do you feel motivated to achieve your goals?	YES	NO	
	Percentage	72%	28%	
	Frequency	18	7	
13.	With sports do you interact with the group with interest and attention?	YES	NO	
	Percentage	72%	28%	
	Frequency	18	7	
14.	Are you attentive and participatory during sports activities?	YES	NO	
	Percentage	92%	8%	
	Frequency	23	2	
15.	Do you feel a sense of well-being after exercising?	YES	NO	
	Percentage	92%	8%	
	Frequency	23	2	
16.	Is it possible to say that thanks to sports the class is satisfied?	YES	NO	
	Percentage	76%	24%	
	Frequency	19	6	

the students feel hindered, 8 % valued and 72 % included. While on question 9, namely 'During sports the subject feels' it turns out that 32% feel valued, 60% included and the remaining 8% hindered. With question 10 'Does sport make you feel better?' 92 % of the students answered yes, while 8 % answered no. Continuing with question 11 'Does sport change your relationship with peers?' 92 % answered yes, while 8 % answered no. In question 12 'With sports do you feel motivated to achieve your goals?' 72 % of the sample answered yes, while 28 % answered no. In question13 'With sports do you interact with the group with interest and attention?' 72% answered yes and the remaining 28% answered no. Continuing with question 14 'Are you attentive and participatory during sports activities?' 92 percent of students answered yes, while 8 percent answered no. Next to question 15 Do you feel a sense of well-being after exercising?' 92% answered yes and the remaining 8 answered no. To conclude with question 16 'Is it possible to say that thanks to sports the class is satisfied?', it turns out that 76 % of the students answered yes, while 24 % answered no. Then with Chi-Quadro analysis, two significant relationships were

Table 3. Table of contigency between question 5 and question 8

Contingency Tables				
5. Sports activities are carried out:	**8. In the classroom the student feels:**			
	hindered	**enhanced**	**included**	**Total**
Not once	0	1	0	1
two/three times a week	4	1	0	5
the activity once/ twice a week	1	0	18	19
Total	5	2	18	25

Table 4. Chi-Quadro result between question 5 and question 8

Chi-Squared Tests	Value	df	p
χ^2	29.947	4	<0.001

detected. Taking question 5 into consideration, the first relationship was detected between it and question 8, with a p=0.001, as is shown in Table 3 and Table 4.

A second significant relationship was found between question 5 and question 9, with a p=0.003, as is shown in Table 5 and Table 6.

Table 5. Table of contingency between question 5 and question 9

Contingency Tables				
5. Sports activities are carried out:	9. During sports the subject feels?			
	hindered	enhanced	included	Total
Not once	0	1	0	1
two/three times a week	2	3	0	5
the activity once/ twice a week	0	4	15	19
Total	2	8	15	25

Table 6. Chi-Quadro result between question 5 and question 9

Chi-Squared Tests	Value	df	p
χ^2	16.118	4	0.003

Discussion

In analyzing the responses, it was found that on average, sports activities are carried out by the most between once and twice a week, nevertheless, a good 20% play sports ⅔ times a week. The responses showed that for most students, sports is fun but for a good percentage it is also a source of well-being; it was also found that for the students surveyed, the relationship with sports is in 80% of cases favorable and positive, small percentages report that there is a relationship of indifference or lack of positivity. The class manifested that they feel valued and included by sports. It was found that enhancement, inclusion and the absence of obstacles are more significant during sports hours than during face-to-face teaching times. In addition, it was found that movement and sports activity increase students' perceived percentages of feeling included and valued. Most students, a good 92 percent of the cases, feel better during sports time, feel they have a better chance of achieving their goals, and say they are involved and attentive during sports activities. Question number 16 manifested that thanks to sports, the class feels satisfied and motivated. It emerged that in the school, sports play a significant role, representing a free time for the children, without prejudice and preconceptions. A substantially positive situation emerges from the study with respect to sports that makes the subjects feel welcomed and valued. Sport initially helps students feel valued and included from the very environment in which they practice (Gould, 2006). A significant relationship, dictated by the chi-square analysis, between the frequency of sports activity and the student's feelings about sports is inferred, with p=0.003, which allows us to understand the positive influence that sports activity has from the very beginning on the practitioners. As shown in the questionnaire and in what is reported in this paper, the presence of sports in school has found positive results from various points of view: sports increase children's sense of well-being and inclusion, and stimulate them to give their best according to skills, knowledge and potential. It is important to understand how there is significance dictated by the ChiQuadro, which makes the overview of the study even more complete. As can be seen from the results, there is a significant relationship between the amount in terms of the frequency of sports activity practiced by students and how the student feels in the classroom, with a p ⅔= 0.001. This means that even with the support of sports activity, the student in the classroom feels more valued as well as included, minimizing negative perceptions in the school environment (Pesce et al., 2013). Sports aims at sharing values, reinforcing self-esteem and promoting a climate of trust and well-being in the classroom (D'Isanto et al., 2019). Thus, a situation prevails in which children are able to grasp the importance of teamwork, the stimulation of motivation and the pre-eminence of confrontation and communication.

Conclusion

The present study focused on the importance of sports in the school setting, aiming to quantify the impact that sports practice has on students in terms of well-being and positive influence. The main conclusion that can be drawn from this study is that sports have a positive impact on students' school life, influencing their physical and emotional well-being, enhancing a sense of inclusion and empowerment, and increasing motivation toward personal goals. The class, in general, says they are satisfied and motivated because of the presence of sports. In view of these findings, the need to recognize and promote the importance of sports in the school setting, not only as a physical activity, but as an effective educational tool for the integral formation of individuals is highlighted. The integration of sports programs into the school routine can contribute significantly to the creation of balanced, resilient and motivated students, preparing them not only for future challenges (work, educational, social), but also by hardening "life and sotf skills" useful for everyday life. Precisely because life and soft skills are recognized as important skills for the individual. The study has a methodological limitation, namely the survey sample, as it is limited in size and stringent inclusion criteria.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Аналіз сприйняття впливу занять спортом на учнів у шкільному середовищі

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 6 табл., 23 джерела.

Мета дослідження. Важливість фізичної активності часто недооцінюється, особливо учнями, навіть попри те, що існують певні наукові докази, що підтверджують цей факт. Також бракує даних щодо сприйняття учнями спортивних практик з точки зору їхнього самопочуття та отримання позитивних результатів під час занять спортом, у тому числі в шкільному середовищі. Метою дослідження є кількісна оцінка впливу занять спортом на стан здоров'я учнів середніх шкіл у навчальному середовищі.

Матеріали та методи. Вибірку досліджуваних склали 25 студентів перших курсів Державного індустріального технічного інституту «Г. Кардано» у м. Павія. Для дослідження взаємозв'язку між станом здоров'я та фізичною активністю учнів було розроблено анкетування, що складалося з 16 питань. Потім відповіді на запитання анкети були проаналізовані із застосуванням критерію хі-квадрат з метою виявлення будь-якої значущості між якісними змінними.

Результати. Встановлено, що для респондентів ставлення до спорту є індиферентним серед 16%, не має позитивного сприйняття для 4% і є сприятливим для 80% опитаних. Аналіз показав, що існує перший значущий зв'язок між частотою занять спортом та самопочуттям студентів в аудиторії під час занять ($p = 0{,}001$), а також другий суттєвий зв'язок між частотою занять спортом та самопочуттям студентів при виконанні фізичної активності ($p = 0{,}003$).

Висновки. Основний висновок, який можна зробити з цього дослідження, полягає в тому, що спортивна активність позитивно впливає на шкільне життя учнів, сприяючи їхньому фізичному та емоційному благополуччю, посилюючи почуття інклюзивності та розширення можливостей, а також підвищуючи мотивацію до досягнення особистих цілей.

Ключові слова: школа, оздоровлення, спорт, анкетування, фізична активність.

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An In-depth Analysis of Multisensory Reaction Time Disparities between Yogic and Non-Yogic Practitioners

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Abstract

Background. Auditory and visual reaction time refers to the duration between the introduction of a sound or light and the onset of a response. It is an important aspect of human behaviour, influencing performance in various activities ranging from daily tasks to sports and emergency situations.

Objectives. The purpose of this study was to investigate reaction time (auditory and visual) as a component of skill-related fitness between male college students practicing yoga and those who do not.

Materials and methods. A total of forty male college-going students (N = 40) were randomly selected to participate in this study. Out of the total, twenty participants (n = 20) were dedicated yoga practitioners actively involved in district and state-level yoga competitions. The remaining twenty individuals (n = 20) followed a sedentary lifestyle and were not involved in yoga practices. The subjects' ages ranged from 17 to 25 years, encompassing a cohort of young adults. The data pertaining to visual reaction time (VRT) and auditory reaction time (ART) was collected using an audio-visual reaction timer. Each participant performed the task thrice, and the mean score was used to indicate the experimental reaction time in milliseconds (ms). Descriptive statistics and the independent samples t-test were subsequently conducted to evaluate the significance level, with a predetermined threshold set at $p < 0.05$.

Results. The results showed that the comparison between VRT and ART of yoga and non-yoga practitioners revealed that for yoga practitioners, $t_{(38)} = 2.91$, and $p < 0.006$, whereas for non-yoga practitioners, $t_{(38)} = 3.55$, and $p < 0.001$. Regarding VRT between yogic and non-yogic practitioners, $t_{(38)} = 1.99$, and $p > 0.054$, and for ART between yogic and non-yogic practitioners, $t_{(38)} = 2.12$, and $p < 0.041$.

Conclusions. The findings suggest that both yogic and non-yogic practitioners demonstrated significantly lower level of ART compared to VRT. Further results indicate that hand speed in terms of VRT is nearly identical between yogic and non-yogic practitioners, but the ART of yogic practitioners was observed to be faster than that of non-yogic practitioners. Yoga has been associated with various physical and mental health benefits, and studies suggest that it may have a positive impact on reaction times.

Keywords: simple reaction time, visual reaction time, auditory reaction time, yogic practitioner, non-yogic practitioner.

Introduction

Reaction time refers to the period between the presentation of a stimulus and the initiation of a response. In various fields such as psychology, sports training, and physiology, reaction time is measured to assess how quickly an individual can respond to a specific stimulus. It is a crucial parameter in understanding cognitive and motor skills, as well as the efficiency of sensory and neural processes. The significance of reaction time in performance is paramount, acting as a dependable gauge of an individual's sensorimotor coordination and overall attentiveness (Balakrishnan et

al., 2014). This assessment of how quickly information is processed in the center and how well-coordinated movements are in the periphery relies on the nervous system's ability to detect stimuli. Neurons send signals to the brain and spinal cord before directing actions to the hands and fingers through motor neurons to execute a suitable response. Reaction time indicates how quickly an organism responds to particular stimuli and is affected by factors like age, gender, handedness, visual concentration, practice, fatigue, fasting, breathing rhythms, personality traits, physical activity, and cognitive capabilities (Jain et al., 2015). In the context of events, reaction time pertains to the ability to swiftly and effectively respond to stimuli such as sound or light, demonstrating quick and suitable posture and control (Reza et al., 2018; Singh & Singh, 2024). Auditory and visual reaction time, vital in this context, denotes the time interval from the introduction of a sound or light stimulus to the commencement of the corresponding response.

Reaction time is a key component in the skill-related aspects of physical fitness, distinct from agility but holding unique significance within the spectrum of physical fitness components. It plays a significant role in various sporting scenarios, with experienced players in soccer demonstrating quicker reaction times compared to their less-experienced counterparts (Theofilou et al., 2022). In sports like basketball, and tennis, rapid reaction times are crucial for adapting promptly to opponents' movements or shots (Bourgase, 2009; Debrousse, 2023). In cricket, for instance, a swift reaction to an edge results in a skillful slip catch. Reaction time is particularly indicative of sprinting ability, where a quick response to the starting signal can significantly impact the outcome of a close race (Jackson, 2017). Athletes dedicate years to training, aiming to enhance reaction time as milliseconds can be the game-changer between victory and missed opportunities. Improving reaction time can lead to heightened on-court efficiency, swifter responses to stimuli, and a decreased likelihood of injuries (Debrousse, 2023). In various activities, spanning from everyday tasks to engagements in sports and emergency situations, optimal performance is associated with improved reaction time in specific situations.

Dutch physiologist Franciscus C. Donders led the way in measuring reaction time in a lab, challenging the prior belief before 1865 that mental processes were too rapid to be measured. Donders (1868), found it intriguing to quantify the duration of fundamental mental processes. The emphasis on precise measurement of reaction time laid the foundation for contemporary psychological experiments, influencing research methodologies to this day (Vinupradha, 2016). The length of cognitive processes is frequently measured in experimental psychology using reaction time (Yadav et al., 2013). Within the realm of cognitive psychology, reaction time serves as a metric for assessing the duration it takes an individual to process information. It has been demonstrated that pharmacological and physiological variables affect reaction time (Mohan et al., 1984; Malathi et al., 1990). According to Annett (1981), the left hemisphere governs motor function in the right hand, while the right hemisphere regulates motor function in the left hand. The mind serves as the motivating factor for actions, as it commands and directs the movements of the limbs in the human body (Rahman & Islam, 2021a). Despite this, the majority of hand patterns are still right-handed, accounting for around 90% of the human population (Scharoun & Bryden, 2014). Researcher has looked into three different kinds of reaction time: simple, recognition, and choice reaction time (Luce, 2008). For assessing routine reaction time in humans, the practicality of utilizing visual, auditory, and tactile neural pathways has been identified (Godlove et al., 2014; Jain et al., 2015).

The holistic approach of yogic practices, as defined by Patanjali, integrates the mastery of the mind and the regulation of stress in individuals (Sonwane & Mishra, 2016). This ancient discipline covers a range of techniques like asana, pranayama, and meditation, all aimed at syncing up your mind and body for optimal harmony (Bagya et al., 2018; Kuppusamy et al., 2017). Through practices like meditation, individuals cultivate mindfulness and awareness, reducing distractions and enhancing their ability to perceive stimuli promptly. Regular participation in yoga leads to improvements in mental well-being, central nervous system processing, and sensorimotor performance (Kuppusamy et al., 2020). The mindful movement, breath control, and mental concentration in yoga positively influence reaction time and overall skill-related fitness. Research shows that yoga enhances sensory-motor conduction velocity, information processing, and concentration, resulting in decreased visual and auditory reaction times (Madanmohan et al., 1992; Madanmohan et al., 2012; Andreou, 2017). The practice of yoga reduces mental fatiguability and increases performance quotient by improving arousal and concentration (Andreou, 2017). Pranayama techniques contribute to heightened concentration and alertness, crucial for faster reactions, as seen in Bhramari pranayama improving cognitive function (Kuppusamy et al., 2020). Yoga poses not only improve coordination and balance but also body awareness and flexibility. It can increase a player's mental and physical relaxation, promote the development of body awareness (Rahman & Islam, 2020), and provide quick responses to external stimuli. Mountain Pose and Warrior I, emphasizing attention to breath, posture, and alignment, contribute to this awareness (Kulkarni, 2023). Visualization techniques and sensory awareness exercises condition the mind and body to react swiftly. Neuroplastic changes induced by yoga lead to improved body awareness, heightened attention, and enhanced present-moment awareness (Castro, 2020). Additionally, the decrease in stress, anxiety, and depression observed after hatha yoga practice optimizes brain function, enhancing cognitive processing and reaction times (Shohani et al., 2018). Practitioners employ concentration techniques during yoga poses, enhancing attentiveness and decreasing reaction time, which holds significance in activities requiring quick responses, such as sports. Thus, the interplay of mindfulness, breath control, and physical postures in yoga creates a holistic foundation for improving reaction time and overall skill-related fitness. Utilizing yogic interventions like integrated yoga, meditation, and pranayama can enhance brain wave activity and cognition, offering an alternative medicine approach to boost performance in games and sports (De & Mondal, 2020; Islam, 2021).

Yoga can have positive effects on cognitive functions, including attention, concentration, and overall mental well-being. Understanding the potential effects of yoga on auditory and visual response time may contribute valuable

insight into the broader cognitive benefits associated with yoga practice. By comparing the reaction times of yogic and non-yogic practitioners, the study seeks to provide empirical evidence of how yoga may or may not affect sensory-motor responses. Therefore, the research aims to explore and examine thoroughly whether individuals engaged in yoga practice exhibit differences in auditory and visual reaction times compared to those who do not practice yoga.

Materials and Methods

Selection of Subjects

A cohort of forty (n = 40) male college-going students from the University of Delhi were selected at random to partake in this study. Among them, twenty individuals (n = 20) were yoga practitioners at the Indira Gandhi Institute of Physical Education and Sports Sciences (IGIPESS), actively participating in district and state-level yoga competitions. The remaining twenty participants (n = 20) were non-yogic practitioners from the School of Open Learning (SOL) and led a sedentary lifestyle. The subjects' ages ranged from 17 to 25, and the data was gathered at the yoga lab of IGIPESS, University of Delhi, India. All participants had normal vision, were free from acute or chronic illnesses and medication use, and abstained from smoking or alcohol consumption during the tests. These undergraduate students volunteered for the study, and it's noteworthy that all participants were right-handed.

Table 1. The characteristics of the Participants (Mean ± SD)

Variables	Yogic Practitioner (n=20)	Non- Yogic Practitioner (n=20)
Age (yr)	21.80 ± 2.16	22.50 ± 1.55
Weight (kg)	59.60 ± 5.67	64.00 ± 4.74
Height (m)	1.67 ± 0.05	1.69 ± 0.06
BMI (kg/m^2)	21.86 ± 1.79	22.70 ± 1.84

Instrument and Tools

The study utilized the Medisystems audio-visual reaction (AVR) timer in India, which is ISO 9001:2015 (QMS) certified. This timer comes with dual functionality, catering to both the researcher and the subject. Each side has four switches and four lights. The switches on the researcher's side control the lights, while those on the subject's side are used to turn off the lights. Additionally, there is a mode featuring four different melodies or tones. The researcher initiates a sound, and the subject's task is to promptly turn it off in the shortest time possible. This setup allows the researcher to assess reaction times using both visual and auditory stimuli. The reaction time of the subject, measured in milliseconds, is considered indicative of their performance (Medi Systems India, n.d.).

Test Administration

The Audio-Visual Reaction (AVR) timer was placed on a table, with subjects comfortably seated in chairs. ART and VRT were quantified in a serene, acoustically controlled environment to optimize focus and eliminate distractions. The reaction time task was conducted between 9 am and noon, an hour after a light breakfast, to maintain consistent conditions. Participants maintained contact between their right index finger and the AVR timer switch while performing tasks. Visual reaction time (VRT) was assessed in response to illuminated lights, while auditory reaction time (ART) was gauged through reactions to low- and medium-pitched sounds. The test administrator, seated across from the subject, controlled the AVR machine, creating lights or sounds of the same amplitude. The AVR timer's LCD display showed reaction time in milliseconds. Each subject repeated the task three times, and the average score represented the experimental reaction time.

Statistical Analysis

After subjecting the data to Levene's test, the researchers confirmed a normal distribution. Statistical analysis involves calculating descriptive statistics, such as the mean and standard deviation (SD). An independent t-test was then performed to determine the significance level, using a pre-established threshold of $p < 0.05$.

Results

Table 2 descriptive analysis of reaction times among yogic and non-yogic groups revealed notable differences. In the yogic group, the mean and SD of VRT were 18.50±1.72, while the ART was 17.20±1.02. On the other hand, the non-yogic group exhibited a higher mean VRT of 19.65±1.93, with a mean ART of 17.90±1.07.

Table 2. Descriptive statistics of reaction time for yogic and non-yogic practitioners

Groups and Parameters		Descriptive		
		Mean (ms)	Std. Deviation	Std. Err. Mean
Yogic	VRT	18.50	1.72	0.38
	ART	17.20	1.02	0.23
Non-Yogic	VRT	19.65	1.93	0.43
	ART	17.90	1.07	0.24
VRT	Yogic	18.50	1.72	0.38
	Non-Yogic	19.65	1.93	0.43
ART	Yogic	17.20	1.02	0.23
	Non-Yogic	17.90	1.07	0.24

In Table 3, the comparison between VRT and ART of yoga and non-yoga practitioners reveals that for yoga practitioners, $t_{(38)} = 2.91$ and $p = 0.006$ (2-tailed). Similarly, for non-yogic practitioners, $t_{(38)} = 3.55$ and $p = 0.001$ (2-tailed). The findings suggest that both yogic and non-yogic practitioners displayed significantly lower ART in comparison to VRT. According to VRT between yogic and non-yogic practitioners, $t_{(38)} = 1.99$, and $p = 0.054$ (2-tailed), and ART between yogic and non-yogic practitioners, $t_{(38} = 2.12$, and $p = 0.041$ (2-tailed). The results show that

Table 3. Reaction time using an independent t-test of yogic and non-yogic practitioners

Groups and Parameters		Mean Difference	Std. Err. Diff.	t	df	Sig. (2-tailed)
Yogic	VRT ART	1.30	0.45	2.91	38	0.006*
Non-Yogic	VRT ART	1.75	0.49	3.55	38	0.001*
VRT	Yogic Non-Yogic	1.15	0.58	1.99	38	0.054
ART	Yogic Non-Yogic	0.70	0.33	2.12	38	0.041*

*Significance at the .05 level

the VRT between yogic and non-yogic practitioners' hand quickness is almost the same, and the ART of yogic practitioners was found to be faster than that of non-yogic practitioners.

Discussion

The findings presented in Table 3 highlight a significant difference in visual reaction time (VRT) compared to auditory reaction time (ART) among both yogic and non-yogic practitioners. This observation aligns with consistent research indicating that individuals engaging in yogic practices tend to have notably shorter ART in comparison to VRT. A noteworthy yoga training program demonstrated a significant decrease in both ART and VRT, with ART experiencing a more pronounced reduction (Ramanathan & Bhavanani, 2020). Further supporting this trend, Şenel and Eroğlu (2006) found significant distinctions between auditory and visual reaction times in male players, with auditory reaction time being superior. The study by Rahman and Islam (2021b) on male university team branch athletes and non-athletes revealed that ART exhibited greater statistical significance compared to VRT in both auditory and visual domains. The physiological aspect of these findings is reflected in the time taken for stimuli to reach the brain, with auditory stimuli taking approximately 8-10 ms and visual stimuli requiring 20-40 ms (Kemp, 1973; Marshall et al., 1943). Consistent with these temporal differences, research by Pain and Hibbs (2007), Shelton and Kumar (2010), and Ghuntla et al. (2014) supports the notion that auditory reaction time surpasses visual reaction time in terms of speed. Researchers Jain et al. (2015) further contributed to this body of knowledge by concluding, based on their study of college students, that auditory reaction time is generally quicker than visual reaction time.

The results of this study indicate that the VRT in terms of hand quickness is nearly identical between yogic and non-yogic practitioners. However, the auditory reaction time (ART) of yogic practitioners was observed to be faster than that of their non-yogic counterparts. This aligns with existing research, such as a study suggesting that yoga practices can significantly improve reaction times, both visually and auditorily (Madanmohan et al., 1992). A meta-analysis further supports the positive impact of yoga on auditory and visual reaction times (Ghuntla & Dholakiya, 2023). Other studies have demonstrated that short-term yoga training can effectively reduce baseline values of auditory, visual, and cutaneous reaction times in healthy individuals (Begum et al., 2012). Additionally, a study implementing a deep relaxation technique reported a notable decrease in both auditory and visual reaction times (Naik, 2021). Contrastingly, studies on visual simple reaction times among different team sports show no significant variations (Reza et al., 2023). Interestingly, hand quickness in simple visual reaction time was found to be similar between university athletes and sedentary students in the population (Rahman et al., 2020). Notably, research has consistently indicated that individuals who do not engage in sports tend to exhibit poorer auditory response times compared to athletes participating in various sports (Atan & Akyol, 2014; Palashikar et al., 2014; Kaplan et al., 2019). The observed reduction in ART and VRT within the yoga group suggests enhanced sensorimotor skills and an improved processing capacity of the central nervous system among individuals practicing yoga (Shobana et al., 2021).

The findings demonstrate that yoga has a positive impact on reaction times, enhanced sensorimotor skills, and improved central nervous system processing capacity due to yoga practice.

Conclusions

In summary, the investigation found that both yogic and non-yogic practitioners exhibited notably reduced auditory reaction time (ART) when compared to visual reaction time (VRT). Additionally, the outcomes suggest that the speed of hand reaction concerning VRT is almost indistinguishable between yogic and non-yogic practitioners. However, it was observed that the ART of yogic practitioners was faster than that of their non-yogic counterparts. The results indicate that regular yoga practice positively influences reaction times, improves sensorimotor skills, and enhances central nervous system processing capacity.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Поглиблений аналіз відмінностей у тривалості мультисенсорної реакції серед осіб, які практикують та не практикують йогу

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 3 табл., 49 джерел.

Історія питання. Час слухової та зорової реакції означає тривалість між поданням звуку або світла і початком реакції. Це важливий аспект людської поведінки, що впливає на ефективність у різних видах діяльності (від повсякденних завдань до спорту та надзвичайних ситуацій).

Мета дослідження. Метою цього дослідження було вивчити час реакції (слухової та зорової) як складової фізичної підготовленості між студентами чоловічої статі, які практикують йогу, та тими, хто не займається даною практикою.

Матеріали та методи. Для участі в цьому дослідженні методом рандомізації було відібрано сорок студентів чоловічої статі (N = 40). Із загальної кількості двадцять учасників (n = 20) були досвідченими практиками йоги, які брали активну участь у змаганнях з йоги на районному та державному рівнях. Решта двадцять осіб (n = 20) дотримувалися малорухливого способу життя і не були залучені до виконання практик йоги. Вік досліджуваних осіб становив від 17 до 25 років, що охоплює когорту молодих дорослих. Дані, що характеризують час зорової реакції (ЧЗР) та час слухової реакції (ЧСР), було зібрано за допомогою аудіо-візуального таймера реакції. Кожен учасник виконував завдання тричі, а середній бал використовувався для визначення експериментального часу реакції в мілісекундах (мс). Для оцінки рівня значущості використовували описову статистику та t-критерій для незалежних вибірок із заздалегідь встановленим пороговим значенням $p < 0,05$.

Результати. За результатами дослідження, порівняльний аналіз рівня ЧЗР та ЧСР між тими, хто практикує і не практикує йогу, показав, що для осіб, практикуючих йогу, значення $t_{(38)} = 2,91$ і $p < 0,006$, тоді як для тих, хто не практикує йогу, рівень $t_{(38)} = 3,55$ і $p < 0,001$. Що стосується ЧЗР між особами, які практикують і не практикують йогу, спостерігалися наступні показники — $t(38) = 1,99$ і $p > 0,054$, а для ЧСР між практикуючими та не практикуючими йогу, рівень $t_{(38)} = 2,12$ і $p < 0,041$.

Висновки. Результати дослідження свідчать про те, що особи, які займаються йогою, і ті, хто не практикують дану техніку, продемонстрували значно нижчий рівень ЧСР порівняно з ЧЗР. Подальші результати вказують на те, що швидкість руху рук при вимірюванні ЧЗР у практикуючих і непрактикуючих йогу майже однакова, однак показники ЧСР у практикуючих йогу були вищими, ніж у осіб, які не практикували йогу. Заняття йогою пов'язують з різними перевагами для фізичного та психічного здоров'я, тому дослідження вказують на те, що така практика може позитивно впливати на час реакції.

Ключові слова: час простої реакції, час зорової реакції, час слухової реакції, особа, яка практикує йогу, особа, яка не практикує йогу.

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Formulating Strategic Directions for Developing the National Sports Federation in Modern Socio-Economic Conditions

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Abstract

Objectives. The study aimed to substantiate theoretical and methodological approaches to choosing a development strategy for the National Sports Federation based on a strategic analysis of its activities in the current socio-economic conditions.

Material and methods. The study involved an analysis of scientific and methodological literature, SWOT-analysis, methods of formalization and generalization, as well as mathematical statistics.

Results. A study was conducted on the activities of the public organization "Fencing Federation of Ukraine" ("FFU" PO) using SWOT analysis, considering the current socio-economic conditions. As a result, the following components of four possible directions of the organization's activities are determined: development strategy, limited-growth strategy, stabilization strategy, and protection strategy. After determining and quantitatively evaluating the factors and quality of the four directions in the "FFU" PO development, while taking into account the trend of world sports development, it can be concluded that the most promising direction for the "FFU" PO activities is a development strategy envisaging the use of the organization's strengths to realize the external environment opportunities.

Conclusions. It is proposed to use a development strategy in the activities of the "FFU" PO — diversification, which envisages innovations in management and marketing, ensuring the financial stability of the organization, improving the quality of athlete training through the introduction of new technologies, and consolidating the organization's positive image.

Keywords: diversification, national sports federation, development strategy, SWOT analysis.

Introduction

The socio-economic transformations in which relations in our society have been developing recently require the sphere of physical culture and sports to search for and substantiate the optimal ways to develop sports events, taking into account the capabilities and needs of society. National sports federations (NSFs) are the main entities in the field of physical culture and sports on which the development of sports events is based. The effectiveness of their activities determines the development of sports event in the country and the performance of athletes in the international arena.

The analysis of recent studies and publications has shown that the efficiency improvement of the activities of the NSF is reflected in the scientific works of national and foreign scientists.

In national science, some issues of statutory and regulatory support governing the activities of the NSF were considered in the works of Morhun (2017), Zozulia and Dovhan (2019). The issues of national NSFs' interaction with international organizations were studied by Kaminska and Paliukh (2018), Driukov, Panin and Driukov (2019). The foreign experience of organizational and managerial activities of the NSFs is described in the works of Bubka and Platonov (2017); Pavlenko (2017); Driukov and Driukov (2022). However, insufficient attention has been paid to the problem of using marketing, which is now becoming an

important element of the state market system and envisages the use of various marketing tools in the activities of the NSFs (Tanklevska & Vybranskyi, 2019).

In foreign science, the publications of Arnold, Fletcher and Hobson (2018); Schleicher, Bauniann and Levy (2018); Ferguson (2022), who studied the role of strategic management in managing sports organizations are of importance for our research. Studies by De Nisi and Murphy (2017); Armstrong (2019); Molan, Kelly, Arnold and Matthews (2019) were aimed at solving certain problems of improving the efficiency of the management system of sports organizations, including some issues of the organization's competitiveness in the international arena.

The analysis of national and foreign scientific and methodological literature on improving the efficiency of the NSFs' activities allowed to identify the problem of the lack of conceptual approaches to the development of strategies (programs) for the development of the NSFs in Ukraine.

Therefore, this insufficiently studied problem is relevant and requires further research.

Thus, in the current economic conditions, the search for ways to form and realize a strategy for the development of the NSFs in the context of modern theories of organizational development assumes great importance (Mintzberg, 2008; Bahorka, Kadyrus & Kravets, 2021; Filho, 2020, etc.)

It should be noted that a necessary element of research, a mandatory preliminary stage in the preparation of any level of strategic programs, according to national (Humeniuk, 2017; Malin, 2020; Halushka, Luste & Hruntovskyi, 2021, et al.) and foreign authors (Bradbury & Galloway, 2021; Wani & Faridi, 2021, et al.) is SWOT analysis.

There are all the necessary organizational and legal grounds for the development and implementation of the NSF development strategy. The "Strategy for the Development of Physical Culture and Sports until 2028" document approved by the Cabinet of Ministers of Ukraine on November 4, 2020, No. 1089, provides for increased autonomy of sports federations, subsidized funding and cooperation and partnership of state and public organizations and creates the basis for the formation of the strategic management process of the NSF and ensuring the unity of further processes to achieve the goals.

Hypothesis. It was assumed that the study and generalization of the main directions and mechanisms of the national sports federation's activities in the current socio-economic conditions using SWOT analysis will allow to substantiate the approach to choosing a strategy for the development of the national sports federation with due account of its socio-economic efficiency.

The objective of the study is to substantiate theoretical and methodological approaches to choosing a development strategy for the national sports federation based on a strategic analysis of its activities in the current socio-economic conditions.

Material and Methods

The study was conducted based on material of the "Fencing Federation of Ukraine" public organization ("FFU" PO). In the course of the study the analysis of scientific and methodological literature and the Internet was used which allowed to collect and systematize material characterizing the main approaches to strategic analysis and planning of the NSF development; SWOT analysis – to identify strengths and weaknesses in the activities of the "FFU" PO, potential external threats and favorable opportunities and their assessment; methods of formalization and generalization – to systematize and draw conclusions; methods of mathematical and statistical analysis – to process and summarize the results.

Procedure

A SWOT analysis was conducted to determine the internal and external factors influencing the development of the "FFU" PO.

At the first stage of the study, 15 competent specialists were selected to conduct a SWOT analysis: employees of the "FFU" PO and the Ministry of Youth and Sports of Ukraine, leading coaches, members of the interdisciplinary research group (IRG) of the Ukrainian national fencing team.

At the second stage, the experts compiled a list of the main factors that can be attributed to the strengths and weaknesses of the "FFU" PO, as well as opportunities and threats of the external environment. Each index had a quantitative evaluation depending on its impact on the organization on the following scale of influence: 3 – strong; 2 – moderate; 1 – weak. The experts' assessment of the ranking of strengths and weaknesses of the internal environment, opportunities, and threats of the external environment are consistent, the calculation of the Kendall's concordance coefficient constituted W=0.87, which indicates a fairly high degree of consistency of their opinions (Table 1).

A SWOT analysis matrix was built at the third stage (Fig. 1) in two vectors: the state of the external environment (horizontal axis) and the state of the internal environment (vertical axis). Each vector was divided into two levels – opportunities and threats identified in the external environment, strength and weakness of the potential of the "FFU" PO. Four fields (quadrants) are formed at the intersections of the individual components of the factor groups.

Each field of the matrix has certain designations:

- The "Strengths-Opportunities" (S/O) field envisages the development of a strategy to support and develop the organization's strengths to realize the opportunities of the external environment.
- The "Strengths-Threats" (S/T) field – focuses the strategy on fighting against threats by using internal reserves (strengths).
- The "Weaknesses-Opportunities" (W/O) field – directs the organization's actions to use opportunities to overcome the weaknesses of its internal potential.
- The "Weaknesses-Threats" (W/T) field – envisages the elaboration of a strategy that would allow the organization to change its potential and avert possible threats in the external environment.

In the fourth stage, based on the construction of the SWOT analysis matrix (Fig. 1), the paired combinations of the strengths and weaknesses of the "FFU" PO with the opportunities and threats in the external environment were considered, which should be taken into account when determining possible strategic measures for the development of the "FFU" PO.

The fifth stage envisaged the analysis of the findings and the formation of strategic directions for the development of the "FFU" PO.

Table 1. The main factors of the internal and external environment of the "FFU" PO

Internal strengths (S)	Estimation, point	Internal weaknesses (W)	Estimation, point
S1. Image of the organization	3	W1. Insufficient amount of financial resources	2
S2. Established cooperation with representatives of state and public authorities in the field of physical culture and sports	3	W2. Lack of a long-term strategy for the development of the organization	1
S3. High level of sports achievements of Ukrainian athletes in the international arena	3	W3. Low salaries and wages	1
S4. Availability of skilled employees to substantiate and implement the directions of the organization's development strategy	3	W4. Insufficient marketing activity	1
External favorable opportunities (O)		**External threats (T)**	
O1. Socio-economic stability in the country	3	T1. Unfavorable socio-economic situation in the country	2
O2. Use of innovative technologies of organizational and managerial activity of the organization	3	T2. Growth of expenses for material and technical support of training of athletes	2
O3. Creation of a general strategy for the development of sports federations using the experience of the world's leading sports	3	T3. Reduction of government funding	2
O4. Bringing the current legal framework that regulates the activities of sports organizations in line with the requirements of the present and international standards	3	T4. Lack of a state-level strategy for the development of sports organizations	1

<table>
<tr><td colspan="3"></td><td colspan="4">External environment</td></tr>
<tr><td colspan="3"></td><td>Opportunities</td><td>Estimation, point</td><td>Threats</td><td>Estimation, point</td></tr>
<tr><td colspan="3"></td><td>1.
2.
etc.</td><td></td><td>1.
2.
etc.</td><td></td></tr>
<tr><td rowspan="4">Internal environment</td><td>Strengths</td><td>Estimation, point</td><td colspan="2" rowspan="2">S/O FIELD (combination of strengths and opportunities)</td><td colspan="2" rowspan="2">S/T FIELD (combination of strengths and threats)</td></tr>
<tr><td>1.
2.
etc.</td><td></td></tr>
<tr><td>Weaknesses</td><td>Estimation, point</td><td colspan="2" rowspan="2">W/O FIELD (combination of weaknesses and opportunities)</td><td colspan="2" rowspan="2">W/T FIELD (combination of weaknesses and threats)</td></tr>
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2.
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Fig. 1. Basic matrix of SWOT analysis (Based on the data of Halushka, Luste & Hruntovskyi, 2021)

Statistical Analysis

Using mathematical statistics methods, a generalized opinion of experts was obtained. The coherence of their opinions was measured by M. Kendall's concordance coefficient. Calculations of the concordance coefficient and verification of its significance are given in detail in the works of many authors (Hrinko, 2021; Yashkin, 2013; Haas & Mortensen, 2016).

The concordance coefficient varies in the range of $0<W<1$, with zero and one corresponding to inconsistency and absolute consistency, respectively. If the value of the concordance coefficient exceeds 0.40-0.50, the quality of the assessment is considered satisfactory, if it is in the range of 0.70-0.80 and above, a high degree of consistency is indicated.

Results

As part of the formation of strategic directions for the development of the "FFU" PO, according to the recommendations of Halushko et al. (2021), a comparison of the strengths and weaknesses of the "FFU" PO with the opportunities and threats of the external environment was

made. The SWOT matrix was used to compare pairwise combinations between internal and external environmental factors and to establish the basis for elaborating possible strategic directions for the development of the "FFU" PO (see Fig. 1).

Let's consider the following combinations:

1. The "Strengths-Opportunities" (S/O) field:

- S1(3) – O1(3). The integral estimation is 6 points (3+3). The positive image of the organization along with the socio-economic stability of the country allows to improve the quality of management at all levels of management by recruiting skilled personnel capable of implementing the adopted development strategy of the "FFU" PO.
- S2(3) – O2(3). The integral estimation is 6 points (3+3). Established cooperation with representatives of state and public authorities in the field of sports management and the use of innovative technologies in the organizational and management activities of the organization provide a favorable field for the elaboration and implementation of the "FFU" PO development strategy.
- S3(3) – O3(3). The integral estimation is 6 points (3+3). The high level of sports achievements of Ukrainian athletes in the international arena and the focus on the general development strategy of sports federations leads to the effective activities of the "FFU" PO.
- S4(3) – O4(3). The integral estimation is 6 points (3+3). The interest of the "FFU" PO leaders in using innovative technologies on the basis of the legal framework that regulates the activities of sports organizations has a favorable field for substantiating and implementing the directions of the organization's development strategy.
- Therefore, the average estimation of the "FFU" PO paired combinations of the factors of the strengths and the opportunities of the external environment constitutes 6 points (3+3). The highest possible estimation forms a strategy that consists in using the strengths of the "FFU" PO to realize the opportunities of the external environment.

2. The "Strengths-Threats" (S/T) field:

- S1(3) – T1(2). The integral estimation is 5 points (3+2). The high reputation of the organization and its employees ensures the stable functioning of the "FFU" PO amid the unfavorable socio-economic situation in the country.
- S2(3) – T2(2). The integral estimation is 5 points (3+2). Close cooperation with representatives of state and public authorities in the field of sports management contributes to marketing activities in the activities of the "FFU" PO, which minimizes the growth of expenditures for material and technical support of athletes' training.
- S3(3) – T3(2). The integral estimation is 5 points (3+2). The high level of sports achievements of Ukrainian athletes in the international arena contributes to attracting additional investments from companies that can be applied to the activities of the "FFU" PO, despite the reduction in budget funding.
- S4(3) – T4(1). The integral estimation is 4 points (3+1). The availability of skilled staff, despite the absence of a strategy for the development of sports organizations at the state level, ensures the stable functioning of the "FFU" PO.

Thus, the average estimation of the "FFU" PO paired combinations of the factors of strengths and external threats constitutes 4.75 points (3+1.75). This estimation suggests a strategy that consists in using the strengths of the "FFU" PO to neutralize external threats.

3. The "Weaknesses-Opportunities" (W/O) field.

- W1(2) – O1(3). The integral estimation is 5 points (2+3). The socio-economic stability in the country minimizes the lack of adequate funding and helps to find additional investors.
- W2(1) – O2(3). The integral estimation is 4 points (1+3). The lack of a long-term strategy for the development of the organization thwarts the progress of the "FFU" PO, despite the possibility of using innovative technologies in its organizational and managerial activities.
- W3(1) – O3(3). The integral estimation is 4 points (1+3). The low salaries of the organization's employees negatively affect the functioning of the "FFU" PO, despite the possibility of creating a general strategy for the development of sports federations, using the experience of the world's leading sports.
- W4(1) – O4(3). The integral estimation is 4 points (1+3). The insufficient marketing activity of the "FFU" PO, as a result of bringing the current legal framework in line with the requirements of today and international standards, may allow for the restructuring of business processes in the work of organizations that will help create favorable conditions for attracting investment resources to the activities of the "FFU" PO.

Therefore, the average estimation of the "FFU" PO pairwise combinations of the factors of weaknesses and opportunities of the external environment constitutes 4.25 points (1.25+3). This estimation envisages a strategy aimed at minimizing the weaknesses of the "FFU" PO through the use of external opportunities.

4. The "Weaknesses-Threats" (W/T) field.

- W1(2) – T1(2). The integral estimation is 4 points (2+2). Insufficient financial resources amid the unfavorable socio-economic situation in the country negatively affect the activities of the organization.
- W2(1) – T2(2). The integral estimation is 3 points (1+2). The lack of a long-term strategy for the development of the organization, as well as the constant increase in the cost of logistics for training athletes, hinder the development of the "FFU" PO.
- W3(1) – T3(2). The integral estimation is 3 points (1+2). Low salaries amid the reduced government funding threaten to lose qualified personnel in the "FFU" PO.
- W4(1) – T4(1). The integral estimation is 2 points (1+1). The activities of the "FFU" PO are limited by insufficient marketing activity of the organization and the absence of a strategy for the development of sports organizations at the state level.

Thus, the average estimation of the "FFU" PO paired combinations of the factors of weaknesses and external threats constitutes 3 points (1.25+1.75). This estimation

Table 2. Matrix of SWOT-analysis of the strategic alternative for the development of the "FFU" PO

Intern environment / External environment	**Opportunities (O) (estimation, point)**	**Threats (T) (estimation, point)**
	O1. Socio-economic stability in the country (3) **O2. Use of innovative technologies in organizational and management activities of the organization (3)** **Strategies for the development of sports federations using the experience of advanced world sports (3)** **O4. Bringing the current legal framework regulating the activities of sports organizations to the requirements of the present and international standards (3).**	**T1. Unfavorable socio-economic situation in the country (2)** **T2. Increased costs of material and technical support for athletes' training (2)** **T3. Reduction of government funding (2)** **T4. Lack of a strategy for the development of sports organizations at the state level (1)**
Strengths (S) (estimation, point) S1. Image of the organization (3) S2. Established cooperation with representatives of state and public authorities in the field of sports management (3) S3. High level of sports achievements of Ukrainian athletes in the international arena (3) S4. Availability of skilled employees to substantiate and implement the directions of the organization's development strategy (3)	An estimation of 6 points (3+3) forms a development strategy that envisages the use of the organization's strengths to realize the opportunities of the external environment	An estimation of 4.75 points (3+1.75) predicts a limited-growth strategy, which is aimed at using the organization's strengths to counter and neutralize threats
Weaknesses (W) (estimation, point) W1. Insufficient financial resources (2) W2. Lack of a long-term strategy for the organization development (1) W3. Low salaries (1) W4. Insufficient marketing activity (1)	An estimation of 4.25 points (1.25+3) focuses on creating a stabilization strategy that aims to minimize the organization's weaknesses in order to take advantage of external opportunities	An estimation of 3 points (1.25+1.75) is considered a defense strategy that is associated with attempts to get rid of both the organization's weaknesses and external threats

envisages a strategy aimed at minimizing the weaknesses of the "FFU" PO and avoiding external threats.

The conducted SWOT analysis based on the comparison of the strengths and weaknesses of the "FFU" PO with external opportunities and threats allowed us to identify four possible directions for the organization's development (Table 2).

The determination and quantification of the factors and quality of the four directions for the development of the "FFU" PO with due account for the trend of world sports development, suggested that the most promising direction will be the development strategy to be realized in cooperation with the state authorities of physical culture and sports management and the establishment of partnerships with business. The development strategy is characterized by diversification (expansion of the organization's activities), which envisages innovations in management and marketing, ensuring the financial stability of the organization, improving the quality of athletes' training through the introduction of new technologies, and strengthening the positive image of the "FFU" PO.

Discussion

The conducted study allowed us to find out that in order to qualitatively prepare national teams for the Olympic Games, governments of many countries adopt state strategies (programs) for the development of elite sports, in which considerable attention is paid to improving the activities of the NSFs (Australia's Winning Edge 2012-2022, 2012; 2019 Canadian High Performance sport Strategy, 2018; Olympiatoppens strategiske utviklings plan 2017-2022, 2017 (Norway) and other strategies (programs) in different countries aimed at systematically addressing the existing issues of the development of elite sports.

An analysis of foreign experience in organizational and legal regulation and management of the NSFs in different countries (Bubka & Platonov, 2017; Pavlenko, 2017; Driukov and Driukov, 2022) has shown that the search for solutions to improve this area is moving towards the use of mixed, flexible forms with the participation of the state, public structures, and private business. At the same time, the state budget retains the function of the main source of funding for the NSFs.

It should be noted that management, which is usually associated with a number of management aspects and features of administration is an effective tool for the development of the NSFs in many countries. For instance, sports management in the United States has fully absorbed the field of sports marketing, which plays a key role in the commercial activities of the NSFs (Driukov, 2020).

Studies have shown that the main differences between Ukrainian and foreign NSFs are the insufficient implementation of advanced marketing technologies, in particular, the use of various marketing tools in the commercial activities of NSFs.

One of the ways of the NSF socio-economic development is to elaborate a development strategy for the organization based on SWOT analysis, with the help of which we have

substantiated the diversification strategy as a strategy to improve the efficiency of the "FFU" PO not only today but also in the long term, with account for the trends in the world sports development, in particular the acceleration of sports commercialization development, as well as the strategic potential of the organization.

It should be noted that until recently, there has been no research in sports science on improving the activities of the NSF in modern socio-economic conditions.

Our research has supplemented and expanded the existing elaborations (Bahorka, et al., 2021; Halushka et al., 2021; Mintzberg, 2008) on strategic analysis and planning of the development of various subjects based on the SWOT analysis methodology to build an effective strategy for the development of the NSF.

These new results are as follows:

- a quantitative assessment of the activities of the NSF in the internal and external environment was obtained for the first time, which allowed to systematize the existing information and make an informed decision on the development of the NSFs in Ukraine under the current conditions;
- for the first time, the Strategy for the development of the NSFs in Ukraine under the current conditions was theoretically substantiated with account for the political, social, and economic effect.

In general, our findings will allow to solve an important state task – to elaborate strategic directions for the development of the NSFs, taking into account the trends in the development of world sports in modern socio-economic conditions.

Conclusions

1. National sports federations have a huge development potential and are not only strategically important subjects of the development of sports events, but also a body that reflects its global status. However, the development of market relations in the field of physical culture and sports has a significant impact on the conditions of the national sports federation's activities, which necessitate the elaboration of ways for the prospective development of the national sports federation with account for the political, social, and economic effect.

2. Based on the SWOT-analysis methodology, a qualitative and quantitative assessment of the activities of the "Fencing Federation of Ukraine" Public Organization ("FFU" PO) from the internal and external environment was obtained. This new knowledge allowed to form and scientifically substantiate a development strategy - diversification, which envisages innovations in management and marketing, ensuring the financial stability of the organization, improving the quality of athletes' preparation through the introduction of new technologies, and strengthening the positive reputation of the "FFU" PO.

Conflict of interest

The authors do not have any conflict of interest.

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Формування стратегічних напрямів розвитку національної спортивної федерації у сучасних соціально-економічних умовах

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 2 табл., 1 рис., 30 джерел.

Мета дослідження – обґрунтування теоретико-методологічних підходів до вибору стратегії розвитку Національної спортивної федерації на основі стратегічного аналізу її діяльності в сучасних соціально-економічних умовах.

Матеріал та методи. У ході дослідження зроблено аналіз науково-методичної літератури, SWOT-аналіз, методи формалізації та узагальнення, математична статистика.

Результати. Проведено дослідження діяльності громадської організації «Федерація фехтування України» (ГО «ФФУ»), яка працює у сучасних соціально-економічних умовах за допомогою SWOT-аналізу. У підсумку визначено складові чотирьох можливих напрямів сфери діяльності організації, а саме – стратегія розвитку, стратегія обмеженого зростання, стратегія стабілізації, стратегія захисту. Визначення та кількісна оцінка факторів та якості чотирьох напрямів розвитку ГО «ФФУ» з урахуванням тенденції розвитку світового спорту дало підставу, вважається що найбільш перспективним напрямом діяльності ГО «ФФУ» буде стратегія розвитку, яка передбачає використання сильних сторін організації для реалізації можливостей зовнішнього середовища.

Висновки. Запропоновано у діяльності ГО «ФФУ» використовувати стратегію розвитку – диверсифікацію, яка передбачає інновації в менеджменті та маркетингу, забезпечення фінансової стійкості організації, підвищення якості підготовки спортсменів внаслідок впровадження нових технологій, закріплення позитивної репутації організації.

Ключові слова: диверсифікація, національна спортивна федерація, стратегія розвитку, SWOT-аналіз.

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Features of Special Physical Training for Female Athletes in Cossack Fight during Different Phases of a Specific Biological Cycle

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Abstract

Background. The training methods for female athletes' special physical training are considered to be a crucial aspect of the overall preparation system for competitive activity, which requires correct planning and implementation.

Objectives. The study aimed to determine the impact of special preparatory exercises on female athletes engaged in Cossack Fight, depending on the characteristics of the body's functioning in different phases of a specific biological cycle.

Materials and methods. The study involved 20 female athletes aged 17-24 years who participated in Cossack Fight, and were divided into experimental and control groups. The qualification levels of female athletes in the experimental group were as follows: 1 – Master of Sports of Ukraine; 2 – Candidates for Master of Sports of Ukraine; 7 – 1 sports category. The control group comprised: 1 – Master of Sports of Ukraine; 2 – Candidates for Master of Sports of Ukraine; 7 – 1 sports category. The training program lasted for ten weeks and took place at a special preparatory and control-preparatory stage of the preparatory period.

Results. The findings showed that the variability of training loads, depending on the phase of the ovarian-menstrual cycle, had a statistically significantly greater impact on the indicators of special physical fitness in the female athletes' experimental group compared to the control group. Thus, after ten weeks of special physical training, the experimental group demonstrated a significant increase in the number of direct punches on the punching bag in 4 seconds ($t=4.07$; $p<0.001$) and 15 seconds ($t=3.62$; $p<0.001$), throwing a medicine ball weighing 3 kg ($t=2.92$; $p<0.05$), repeated circular kicks on the punching bag to the torso level for 15 seconds ($t=4.22$; $p<0.001$), direct punches on the punching bag for 1 minute ($t=4.23$; $p<0.001$), repeated circular kicks on the punching bag for 1 minute ($t=4.49$; $p<0.001$), and jumping rope after exercise (a 3-minute punching bag workout) for 1 minute ($t=3.55$; $p<0.001$).

Conclusions. The implementation of an experimental program for special physical training of female athletes, in accordance with the phases of the ovarian-menstrual cycle, into the general system of preparation for competitive activity, leads to a statistically reliable improvement in key indicators of physical fitness.

Keywords: cossack fight, special physical training, training process, ovarian-menstrual cycle.

Introduction

One of the main trends in the development of modern martial arts in the world is the increase every year in the number of women who systematically train and compete in sports competitions. The same trend can be clearly seen in the Ukrainian national form of combat sport – the Cossack Fight (Lytvynenko, 2023; Lytvynenko, Mulyk, 2023). An analysis of special literature on the theory and methodology of sports training for women shows that in many works the authors study the structural features and physiological processes of the female body in connection with reproductive function (Alfaro-Magallanes, Romero-Parra, 2023; Shakhlyna et al., 2016; Badenhorst et al., 2021). A number of studies reveal the peculiarities of the functioning of the female body and psychological processes under the influence of significant physical activity in different phases of the ovarian-menstrual cycle (OMC) (Vorontsov, 2020; Arenas-Pareja & López-Sierra, Ibáñez, 2023). The works Mulyk (2016) Shakhlina, Chystyakova, and Avinov (2022), shows differences in the structure and functioning of the female body and the level of development of physical and psychophysical qualities depending on biological age and experience in sports. A number of studies (Shakhlina,

2021; Lysenko, Hasanova, Shynkaruk, 2021) are devoted to the influence of sex hormones on the dynamics of physical performance during the training of women in various sports. Experts have established the dependence of the performance indicators of female athletes in certain sports and the reaction of their body to training loads depending on changes in the concentration of sex hormones in different phases of OMC (Janse de Jonge, 2003; Kanunova et al., 2020). A number of studies have shown the individual dynamics of changes in the performance of female athletes in individual phases of OMC (Alfaro-Magallanes et al., 2023; Baranauskas et al., 2023).

The training process of highly qualified female athletes in martial arts shows that with each decade it becomes more and more specialized (Shakhlina, 2021; Lytvynenko, Mulyk, 2023). According to researchers, this is due to the need for the greatest compliance of means and methods of sports training with the requirements of competitive activity. The priority of developing speed-strength qualities to achieve maximum competitive results of female athletes in martial arts is shown in the works (Ashanin, & Lytvynenko, 2023). Analysis of data from specialized literature on combat sports and our own research show that the volume and intensity of training loads of female athletes in Ukrainian national types of combat sports have reached natural limits and it is necessary to search for new ways to improve sports training (Mulyk, & Dzhym, 2017).

The issues of constructing special physical training of female athletes of Ukrainian national martial arts, taking into account changes in the physiological indicators of women in various phases of a specific biological cycle, have not been sufficiently studied.

Purpose of the study. To determine the impact of the use of special preparatory exercises on female athletes engaged in Cossack Fight, depending on the characteristics of the functioning of the body in different phases of a specific biological cycle.

Materials and methods

Participants

The sample of this study included 20 qualified female athletes from the Cossack Fight aged 17-24 years, divided into experimental and control groups. Qualification level of athletes of the experimental group: 1 – master of sports of Ukraine; 2 – candidate master of sports of Ukraine; 7 – 1 sports category, control group: 1 – master of sports of Ukraine; 2 – candidate master of sports of Ukraine; 7 – 1 sports category.

Organization of the Study

The following research methods were used: theoretical analysis and generalization of data from specialized literature, methods of pedagogical control (testing of motor qualities, pedagogical observations, methods for determining a specific biological cycle (measurement of oral-basal temperature, crystallization of nasal mucus), methods of mathematical statistics).

The training programs lasted ten weeks and took place at special preparatory and control-preparatory stages of the preparatory period.

The following research methods were used: theoretical analysis and generalization of data from specialized literature, methods of pedagogical control (testing of motor qualities, pedagogical observations, methods for determining a specific biological cycle (measurement of oral-basal temperature, crystallization of nasal mucus), methods of mathematical statistics).

The training programs lasted ten weeks and took place at special preparatory and control-preparatory stages of the preparatory period (fig. 1).

Testing Procedure

Testing took place during a control training session, at the same time for each participant, under the same conditions, without injuries, in a good emotional state. Before testing, participants performed an individual warm-up. Immediately before performing the test exercises, participants were instructed to exert maximum effort. Test exercises were used that were standard for determining the level of special physical fitness in martial arts of striking, wrestling and mixed types: direct punches on a bag for 4 s, straight punches on a bag for 15 s, throwing a medicine ball weighing 3 kg, repeated circular kicks on the bag to the level of the torso for 15 s, double leg takedown for 20 s, running onto the "springboard" around the head, 5 times to the right and left, dynamometry of the muscles of the leading hand, direct punches to the bag for 3 min, repeated circular kicks to the level of the body for 1 minute, jumping rope after exercise (work on a bag lasting 3 minutes) in 1 minute

Statistical Analysis

The research materials were processed in the statistical analysis program – IBM SPSS 20. The following statistics were calculated for each variable: mean value (X), standard deviation (s), standard deviation error (m), Student's t-test for independent and pairwise related samples.

Results

Testing at the beginning of the retracting microcycle did not reveal a significant difference between the study groups in indicators of special preparedness (Table 1).

Periods	Preparatory								
Stages	Special preparatory						Control preparatory		
Mesocycles	Retracting from SPP and STP		Basic from SPP and STP				Control preparatory		
Microcycles	Rt	Rs	Sh	Rs	Sh	Rs	Cp	Rs	Cp

Fig. 1. Structure of the specially preparatory and control preparatory stages of the preparatory period. Note: Microcycles: Rt – retractor, Sh – shock, Rs – restorative, Cp – control preparatory

After the end of the special preparatory stage (basic mesocycle for special training and control and preparatory mesocycle), repeated testing was carried out, the results of which are presented in Table 2.

As evidenced by the data obtained for most indicators corresponding to the manifestation of special motor actions, such as direct punches to the bag for 4 s, 15 s and 3 min, repeated circular kicks on the bag to the level of the torso for 15 s and in 1 minute, as well as Jumping rope after exercise for 1 minute, significantly better results were obtained from female athletes in the experimental group (p<0,05).

In addition, during the implementation of the experimental program, the results in terms of the number of direct punches on the bag in 4 s (t = 4.07; p < 0.001) and in 15 s increased significantly (t=3.62; p<0.001), throwing a medicine ball weighing 3 kg (t=2.92; p<0.05), repeated circular kicks on the bag to the level of the body in 15 s (t=4.22; p<0.001), direct punches to the bag for 1 min (t=4.23; p<0.001), repeated circular kicks to the bag for 1 min (t=4.49; p<0.001) and jumping rope after exercise (work on the bag for 3 minutes) for 1 minute (t=3,55; p<0,001) (Table 3).

Along with this, less significant changes were obtained in the control group (Table 4).

Discussion

The main results of our study revealed noticeable differences, in terms of indicators of special physical fitness, between the experimental and control groups of female Cossack Fight athletes. The variability of training loads depending on the phase of OMC made it possible to improve the indicators of special physical fitness of the experimental group of female athletes compared to the control group. During the implementation of the experimental program, the results in terms of the number of direct punches to the bag for 4 s, increased significantly (t=4.07; p<0.001) and in 15 s (t=3.62; p<0.001), throwing a medicine ball weighing 3 kg (t=2.92; p<0.05), repeated circular kicks on the bag to the level of the torso for 15 s (t=4.22; p<0.001), direct punches on the bag for 1 min. (t=4.23; p<0.001), repeated circular kicks to the level of the torso for 1 min (t=4.49; p<0.001) and jumping rope after exercise (work on a bag lasting 3 minutes) in 1 min (t=3.55; p<0.001).

Table 1. Results of testing indicators of special physical preparedness of qualified female athletes in the Cossack Fight (competition section Hertz 3) of the control and experimental groups at the beginning of the special preparatory stage of annual training (n1=n2=10), (X±m)

No	Test exercises	Control group	Experimental group	t	p
1	Direct punches to the bag for 4 s, times	8.1±0.18	8.0±0.17	0.42	>0.05
2	Direct punches to the bag for 15 s, times	35.3±0.46	36.1±0.48	1.21	>0.05
3	Throwing a medicine ball weighing 3 kg, m	6.5±0.16	6.4±0.16	0.44	>0.05
4	Repeated circular kicks on the bag to the level of the torso for 15 s, times	15.5±0.31	15.3±0.30	0.46	>0.05
5	Double leg takedown in 20 s., times	10.9±0.20	10.8±0.19	0.38	>0.05
6	Running on the "springboard" around the head, 5 times to the right and left, s	33.0±0.41	32.7±0.40	0.53	>0.05
7	Dynamometry of the muscles of the leading hand, kg	29.3±0.39	29.5±0.40	0.36	>0.05
8	Direct punches on the bag for 3 minutes, times	189.9±2.11	186.7±2.10	1.08	>0.05
9	Repeated circular kicks to the level of the torso for 1 min, times	39.9±0.48	39.2±0.47	0.56	>0.05
10	Jumping rope after exercise (work on a bag lasting 3 minutes) in 1 min, times	59.9±0.52	60.0±0.50	0.40	>0.05

Table 2. Results of testing indicators of special physical fitness of qualified female athletes in the Cossack Fight (competition section Hertz 3) of the control and experimental groups at the end of the study (n1=n2=10), (X±m)

No	Test exercises	Control group	Experimental group	t	p
1	Direct punches to the bag for 4 s, times	8.4±0.20	9.1±0.21	2.42	<0.05
2	Direct punches to the bag for 15 s, times	36.7±0.47	38.6±0.50	2.75	<0.05
3	Throwing a medicine ball weighing 3 kg, m	6.8±0.50	7.1±0.18	1.00	<0.05
4	Repeated circular kicks on the bag to the level of the torso for 15 s, times	15.8±0.32	17.2±0.33	3.04	<0.01
5	Double leg takedown in 20 s, times	10.9±0.20	11.1±0.22	0.71	>0.05
6	Running on the "springboard" around the head, 5 times to the right and left, s	33.0±0.41	32.5±0.40	0.88	>0.05
7	Dynamometry of the muscles of the leading hand, kg	30.2±0.38	30.6±0.39	0.74	>0.05
8	Direct punches on the bag for 3 minutes, times	192.3±2.12	199.4±2.14	2.36	<0.05
9	Repeated circular kicks to the level of the torso for 1 min, times	40.4±0.49	42.3±0.51	2.68	<0.05
10	Jumping rope after exercise (work on a bag lasting 3 minutes) in 1 min, times	60.4±0.54	69.7±0.57	2.95	<0.05

Table 3. Results of testing indicators of special physical fitness of qualified athletes in the Cossack Fight (competition section Hertz 3) of the experimental group at the beginning and at the end of the study (n=10), (X±m)

No	Test exercises	At the beginning	At the end	t	p
1	Direct punches to the bag for 4 s, times	8.0±0.17	9.1±0.21	4.07	<0.001
2	Direct punches to the bag for 15 s, times	36.1±0.48	38.6±0.50	3.62	<0.001
3	Throwing a medicine ball weighing 3 kg, m	6.4±0.16	7.1±0.18	2.92	<0.05
4	Repeated circular kicks on the bag to the level of the torso for 15 s, times	15.3±0.30	17.2±0.33	4.22	<0.001
5	Double leg takedown in 20 s, times	10.8±0.19	11.1±0.22	1.03	>0.05
6	Running on the "springboard" around the head, 5 times to the right and left, s	32.7±0.40	32.5±0.40	0.51	>0.05
7	Dynamometry of the muscles of the leading hand, kg	29.5±0.40	30.6±0.39	1.96	>0.05
8	Direct punches on the bag for 3 minutes, times	186.7±2.10	199.4±2.14	4.23	<0.001
9	Repeated circular kicks to the level of the torso for 1 min, times	39.2±0.47	42.3±0.51	4.49	<0.001
10	Jumping rope after exercise (work on a bag lasting 3 minutes) in 1 min, times	60.0±0.50	62.7±0.57	3.55	<0.001

Table 4. Results of testing indicators of special physical fitness of qualified athletes in the Cossack Fight (competition section Hertz 3) of the control group at the beginning and at the end of the study (n=10), (X±m)

No	Test exercises	At the beginning	At the end	t	p
1	Direct punches to the bag for 4 s, times	8.1±0.18	8.4±0.20	1.15	>0.05
2	Direct punches to the bag for 15 s, times	35.3±0.46	36.7±0.47	2.12	<0.05
3	Throwing a medicine ball weighing 3 kg, m	6.5±0.16	6.8±0.17	1.30	>0.05
4	Repeated circular kicks on the bag to the level of the torso for 15 s, times	15.5±0.31	15.8±0.32	0.67	>0.05
5	Double leg takedown in 20 s, times	10.9±0.20	10.9±0.20	0.0	<0.05
6	Running on the "springboard" around the head, 5 times to the right and left, s	33.0±0.41	33.0±0.41	0.0	<0.05
7	Dynamometry of the muscles of the leading hand, kg	29.3±0.39	30.2±0.38	1.67	>0.05
8	Direct punches on the bag for 3 minutes, times	189.9±2.11	192.3±2.12	0.80	>0.05
9	Repeated circular kicks to the level of the torso for 1 min, times	39.9±0.48	40.4±0.49	0.26	>0.05
10	Jumping rope after exercise (work on a bag lasting 3 minutes) in 1 min, times	59.9±0.52	60.4±0.54	0.21	>0.05

The results of the study complement the data on increasing the speed and coordination capabilities of female athletes specializing in judo in the postmenstrual and postovulatory phases of the ovarian-menstrual cycle (Shakhlina et al., 2022).

The data obtained confirm the information that periodic changes in hormonal levels in the female body affect the ability to adequately respond to training loads (Bosenko, Orlik, & Palshkova, 2019; Dzhym, 2017; Kyrychenko, 2021; Kanunova, & Piven, 2020), the data obtained confirm the information that periodic changes in hormonal levels in the female body affect the ability to adequately respond to training loads. (Mulyk, 2016; Bosenko, Orlik, & Palshkova, 2019; Shakhlina, Chystyakova, Avinov, 2022).

The results of the study can be used to improve the training system for female athletes in the types of combat sports of striking, wrestling and mixed types.

In future works, the authors plan to study the dynamics of indicators of psychophysiological qualities of female athletes in Ukrainian national types of combat sports.

Conclusions

A significant increase in the number of female athletes involved in Ukrainian national types of combat sports requires a theoretical justification of approaches to building the training process and the formation of special physical training methods taking into account the specific biological cycle. The use of significant and heavy loads in the training process for special physical training in the postmenstrual and postovulatory phases of a specific biological cycle and a decrease in load in other phases of OMC contributes to a significant increase in the indicators of special physical fitness of female athletes. The use of special preparatory exercises at the end of a training session against the background of fatigue in the phases of increased performance of female athletes (postmenstrual and postovulatory) makes it possible to increase the competitive performance of female athletes in the combat sports of Cossack Fight.

Conflict of interest

The authors guarantee that there is no conflict of interest.

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Особливості спеціальної фізичної підготовки жінок-спортсменок у козацькому двобої в різних фазах специфічного біологічного циклу

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 4 табл., 1 рис., 30 джерел.

Історія питання. Тренувальні методики спеціальної фізичної підготовки спортсменок-жінок є важливою частиною загальної системи підготовки до змагальної діяльності, що потребує коректного планування та реалізації.

Мета дослідження. Визначити вплив застосування спеціально-підготовчих вправ на жінок-спортсменок з козацького двобою, в залежності від особливостей функціонування організму в різних фазах специфічного біологічного циклу.

Матеріали та методи. В експерименті взяли участь 20 жінок-спортсменок з козацького двобою віком 17-24 років поділених на експериментальну та контрольну групи. Кваліфікаційний рівень спортсменок експериментальної групи: 1 – майстер спорту України; 2 – кандидат у майстри спорту України; 7 – 1 спортивний розряд, контрольної групи: 1 – майстер спорту України; 2 – кандидат у майстри спорту України; 7 – 1 спортивний розряд. Програма тренувань тривала десять тижнів і проходила на спеціальному підготовчому та контрольно-підготовчому етапах підготовчого періоду.

Результати. Варіативність тренувальних навантажень в залежності від фази овариально-менструального циклу має статистично достовірно більший вплив на показники спеціальної фізичної підготовленості експериментальної групи жінок-спортсменок у порівнянні з контрольною групою. Так, в експериментальній групі після десяти тижнів тренувань із спеціальної фізичної підготовки суттєво підвищилися результати в показниках кількості прямих ударів руками по мішку за 4 с ($t=4,07$; $p<0,001$) та за 15 с. ($t=3,62$; $p<0,001$), метанні набивного м'яча масою 3 кг ($t=2,92$; $p<0,05$), повторних колових ударів ногами по мішку на рівень тулуба за 15 с ($t=4,22$; $p<0,001$), прямих ударів руками по мішку за 1 хв ($t=4,23$; $p<0,001$), повторних колових ударів ногами по мішку за 1 хв ($t=4,49$; $p<0,001$) та стрибків зі скакалкою після навантаження (робота на мішку тривалістю 3 хв) за 1 хв. ($t=3,55$; $p<0,001$).

Висновки. Впровадження експериментальної програми із спеціальної фізичної підготовки жінок-спортсменок у відповідності до фаз овариально-менструального циклу в загальну систему підготовки до змагальної діяльності статистично достовірно покращує ключові показники фізичної тренованості.

Ключові слова: козацький двобій, спеціальна фізична підготовка, тренувальний процес, овариально-менструальний цикл.

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Predicting Team Success in the Indian Premier League Cricket 2024 Season Using Random Forest Analysis

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Abstract

Background. Random Forest is a popular machine learning algorithm used for classification and regression tasks. The study purpose is to investigate the use of Random Forest machine learning to predict the winning chances of teams in the 2024 Indian Premier League (IPL) season.

Objectives. By analyzing comprehensive player statistics, including matches played, batting and bowling averages, as well as fielding contributions, the study aims to understand the factors that influence team success in T20 cricket and provide actionable insights for team management, betting markets, and cricket enthusiasts.

Material and methods. The study involved 10 cricket teams competing in the IPL 2024 season. Player statistics and match outcomes data from previous IPL seasons were collected and cleaned, with missing values addressed through imputation. The features were based on player statistics, including both aggregate measures and calculated metrics. A Random Forest is chosen as the machine learning model, trained using preprocessed data, with features derived from player statistics as input and match outcomes as the target variable. The dataset was split into training and validation sets, using methodologies such as cross-validation to ensure a robust model performance.

Results. The Random Forest model demonstrates strong predictive performance, with a low Mean Squared Error (MSE) of 8.2174, Root Mean Squared Error (RMSE) of 2.8666, and a high R-Squared value of 0.9173, indicating approximately 91.73% variance explained in the data. Chennai Super Kings emerge as frontrunners with a predicted performance percentage of 83.4%, while teams like Punjab Kings and Lucknow Super Giants show lower predicted performance percentages, suggesting potential areas for its improvement.

Conclusions. This study reveals the effectiveness of Random Forest machine learning in forecasting IPL match outcomes based on player statistics. It provides valuable insights into team dynamics and offers actionable recommendations for team management and cricket enthusiasts. The findings enrich our understanding of IPL match dynamics, contribute to the evolution of cricket analytics, and promote greater engagement with sport, ultimately enhancing the fan experience in the IPL.

Keywords: Indian Premier League, Random Forest, machine learning, team performance prediction, cricket analytics.

Introduction

Cricket, often described as a gentleman's game, has transcended its traditional boundaries to become a global phenomenon, captivating audiences with its blend of athleticism, strategy, and sheer spectacle. Within this vibrant tapestry of cricketing culture, the Indian Premier League (IPL) stands as a beacon of innovation, drawing players from across the cricketing world and electrifying audiences with its fast-paced format and star-studded line-ups (Subburaj et al., 2023; Kapadia et al., 2022).

The Indian Premier League (IPL) stands as a testament to the global appeal and excitement surrounding cricket, captivating audiences worldwide with its blend of athleticism, drama, and sheer spectacle. As the cricketing world gears up for the upcoming IPL season in 2024, anticipation is at an all-time high, with fans eagerly awaiting the clash of titans and the quest for supremacy on the field (Sanjaykumar et al., 2023). Central to the IPL's allure is the element of unpredictability, where every match is a battleground where teams vie for victory, driven by a potent mix of skill, strategy, and determination. In this dynamic and ever-evolving landscape, the ability to forecast winning chances emerges as a tantalizing challenge, offering valuable insights into the intricate dynamics that shape match outcomes (Passi and Pandey, 2018; Sumathi et al., 2023).

The Random Forest machine learning technique is a versatile algorithm renowned for its effectiveness in handling complex datasets. It operates by aggregating the predictions of multiple decision trees, mitigating overfitting through feature selection and bootstrap sampling. With its ability to handle high-dimensional feature spaces and deliver robust predictions, Random Forest stands out as a valuable tool in sports analytics. By leveraging historical data, it can uncover patterns and identify key factors influencing outcomes, making it particularly well-suited for predicting player performance, match results, and tournament dynamics in sports like cricket (Abebe et al., 2020; Passi & Pandey, 2018).

The IPL, with its fast-paced format and star-studded line-ups, presents a unique challenge for predicting winning chances. Team dynamics, player form, pitch conditions, and match strategy all play pivotal roles in shaping the outcome of a match, demanding a nuanced and data-driven approach to analysis (Wickramasinghe, 2014; Bai & Bai, 2021).

Moreover, the IPL's evolving ecosystem, marked by player auctions, tactical innovations, and fluctuating fortunes, adds another layer of complexity to the prediction task. While historical data provides a foundation for analysis, it must be complemented by real-time insights and contextual understanding to capture the dynamic nature of the tournament accurately (Aburas et al., 2018; Bunker and Thabtah, 2019). By leveraging a comprehensive dataset encompassing past IPL seasons, player statistics, match conditions, and other pertinent variables, we aim to develop a predictive model capable of estimating the likelihood of each team winning a match in the upcoming season. Through rigorous analysis and validation, we seek to uncover the underlying patterns and trends that drive match outcomes in the IPL (ESPNcricinfo; Indian Premier League official website).

The purpose of the research. To employ Random Forest machine learning to predict winning chances of teams in the 2024 Indian Premier League season. By analyzing comprehensive player statistics, including the number of matches played, batting and bowling averages, and fielding contributions, we aim to understand the factors that influence team success in T20 cricket. The implications of the study extend beyond mere prediction, offering actionable insights for team management, betting markets, and cricket enthusiasts alike. By identifying key factors that influence winning chances, teams can optimize their strategies, fine-tune their player selections, and enhance their competitive edge in the tournament.

Material and Methods

Participants

The participants of this study encompass 10 cricket teams slated to compete in the upcoming Indian premier league t20 2024. These teams represent diverse cricketing franchises and comprise professional players selected to represent their teams in the tournament. The dataset utilized for analysis comprises player statistics and match outcomes sourced from previous IPL and other pertinent t20 tournaments leading up to the IPL t20 cricket tournament 2024 (ESPNcricinfo; Indian Premier League official website).

Study Organization

Comprehensive player statistics, including the number of matches played, batting averages, bowling averages, and fielding contributions (e.g., catches taken), are gathered for each player participating in the IPL 2024 in Indian premier league official website (figure 1).

Matches	Batting_Avg	Bowling_Avg	Catches
186	32.140000	24.070000	67.000000
44	17.310000	30.340000	8.000000
78	7.300000	24.310000	17.000000
30	6.160000	20.010000	6.000000
90	10.000000	25.620000	13.000000
94	8.400000	25.500000	29.000000
25	44.300000	0.000000	13.000000

Fig. 1. Sample dataset

The collected data undergoes meticulous cleaning to rectify inconsistencies or inaccuracies, with missing values addressed through imputation or suitable handling techniques Relevant features are derived from player statistics, incorporating aggregate measures and calculated metrics (Sanjaykumar et al., 2023; Vetukuri et al., 2019). A random forest is chosen as the machine learning model for predicting match outcomes. The model is trained using the preprocessed data, with features derived from player statistics as input and match outcomes as the target variable. The dataset is split into training and validation sets, employing methodologies like cross-validation to ensure robust model performance (Hudnurkar & Rayavarapu, 2022; Baboota & Kaur, 2019).

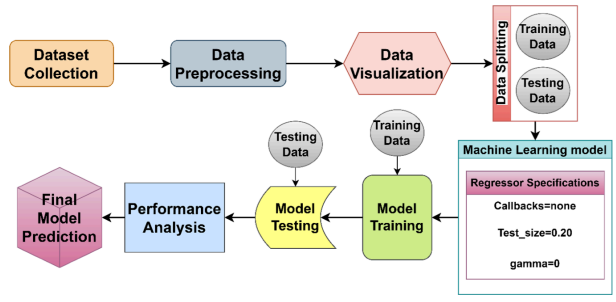

Fig. 2. Methodological architecture of random forest training model

Statistical Analysis

To evaluate the employ Random Forest machine learning to predict winning chances of teams in the 2024 Indian Premier League cricket season. Random Forest, several statistical metrics are employed, these metrics include Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and the R-squared Metric (R^2). The MSE quantifies the average of the squared differences between predicted and actual performance values, while RMSE represents the square root of this average, maintaining the same units as the original data. MAE assesses the average absolute variance between predicted and observed performance values, and R^2 evaluates the goodness of fit of the model, ranging from 0 to 1 (Wickramasinghe, 2020; Lakshmi et al., 2024).

$$\text{Mean Squared Error (MSE)} = \frac{1}{a} * \sum\left(X_{predict} - X_{actual}\right)^2$$

$$\text{Root Mean Squared Error (RMSE)} = \sqrt{MSE}$$

$$\text{R-Squared (R2)} = 1 - \left[\frac{\sum(X_{actual} - X_{predict})^2}{\sum(X_{actual} - X_{mean})^2}\right]$$

In the provided equation, X_{actual} represents the observed performance values, $X_{predict}$ denotes the predicted performance, X_{mean} stands for the mean of the actual performance values, and "a" symbolizes the number of data points. This equation serves as a crucial tool in calculating the R-squared Metric (R^2), which assesses the goodness of fit of predictive models by measuring the proportion of variance in the dependent variable (match outcomes, in this context) that is explained by the independent variables (player statistics).

Results

The results presented here serve to enrich our understanding of IPL match dynamics, providing valuable insights that can inform decision-making processes and enhance the fan experience. Through a combination of data-driven analysis, we aim to contribute to the ongoing evolution of cricket analytics and promote greater engagement with the sport.

Table 1. Random Forest Model Performance Metrics analysis

	Metrics	Value
Random Forest (RF) Model	Mean Square Error	8.2174
	Root Mean Square Error	2.8666
	R-Squared	0.9173

The Random Forest (RF) model exhibits strong predictive performance, as evidenced by the low Mean Square Error (MSE) of 8.2174 and Root Mean Square Error (RMSE) of 2.8666. The R-Squared value of 0.9173 indicates that the model explains approximately 91.73% of the variance in the data, suggesting a high level of accuracy in predicting team winning chances (Table 1). These metrics collectively demonstrate the effectiveness of the RF model in forecasting IPL match outcomes, providing valuable insights for stakeholders and decision-makers (Fig. 3).

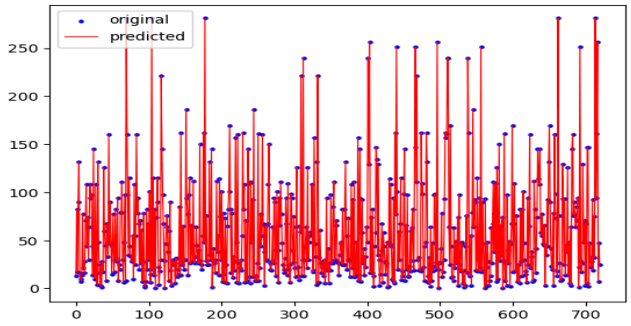

Fig. 3. Performance prediction graph for a random forest model

Team Performance Predictions

Based on the study's purpose of employing Random Forest machine learning to predict winning chances, a comprehensive analysis reveals significant insights. Chennai Super Kings emerge as the frontrunners with a predicted performance percentage of 83.4%, aligning with the aim of the study to forecast team success. This suggests that factors such as player statistics, including matches played, batting and bowling averages, and fielding contributions, contribute to Chennai Super Kings' favorable outlook for the upcoming IPL season. Conversely, teams like Punjab Kings (71.2%) and Lucknow Super Giants (73.8%) display lower predicted performance percentages, indicating potential areas for improvement in their player statistics and team dynamics (Fig. 4).

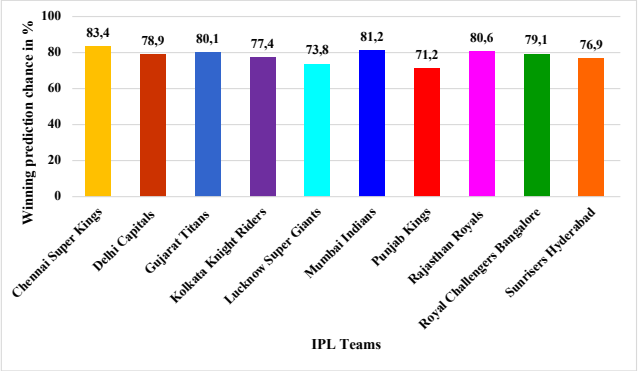

Fig. 4. Performance prediction (percentage) of Indian premier league cricket teams

Discussions

The research study employs Random Forest machine learning to predict the winning chances of teams in the 2024 Indian Premier League (IPL) season. By analyzing comprehensive player statistics, including matches played, batting and bowling averages, and fielding contributions, the study aims to understand the factors influencing team success in T20 cricket (Sanjaykumar et al., 2023; Saikia, 2020). The Random Forest model's performance metrics, including a low Mean Square Error (MSE) of 8.2174, Root Mean Square Error (RMSE) of 2.8666, and an R-Squared value of 0.9173, demonstrate its effectiveness in forecasting IPL match outcomes (Table 1). These metrics indicate a high level of accuracy in predicting team winning chances,

providing valuable insights for stakeholders and decision-makers (Kaur et al., 2021).

The performance prediction graph of IPL teams based on the Random Forest model highlights Chennai Super Kings as the frontrunners with a predicted performance percentage of 83.4%. This aligns with the study's aim of forecasting team success and suggests that player statistics, such as matches played, batting and bowling averages, and fielding contributions, contribute to Chennai Super Kings' favorable outlook for the upcoming IPL season. Conversely, teams like Punjab Kings (71.2%) and Lucknow Super Giants (73.8%) display lower predicted performance percentages, indicating areas for improvement in their player statistics and team dynamics (Fig. 4) (Bhattacharjee & Talukdar, 2020; Van Eetvelde et al., 2021).

The study enriches our understanding of IPL match dynamics and provides actionable insights for team management, betting markets, and cricket enthusiasts. By identifying key factors that influence winning chances, teams can optimize strategies, fine-tune player selections, and enhance their competitive edge (Men, 2022; Turhan & Canpolat, 2023). The study's combination of data-driven analysis and advanced modeling techniques contributes to the ongoing evolution of cricket analytics and promotes greater engagement with the sport, ultimately enhancing the fan experience and decision-making processes in the IPL (Šuštaršič et al., 2022; Gu et al., 2023).

Conclusions

This study employs Random Forest machine learning to forecast team winning probabilities for the 2024 Indian Premier League (IPL) season, utilizing a wide array of player statistics such as matches played, batting and bowling averages, and fielding contributions. The model demonstrates robust predictive capability, reflected in the low Mean Square Error (MSE) of 8.2174, Root Mean Square Error (RMSE) of 2.8666, and high R-Squared value of 0.9173, signifying an explanatory power of approximately 91.73% in the data variance. Chennai Super Kings emerge as the favored contenders with a predicted performance percentage of 83.4%, in accordance with the study's objective of gauging team success. Conversely, Punjab Kings (71.2%) and Lucknow Super Giants (73.8%) exhibit lower predicted performance percentages, implying potential areas for enhancement in player statistics and team dynamics.

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Conflict of Interest

We declare no conflicts of interest regarding the publication of this study.

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Прогнозування успішності команд в Індійській прем'єр-лізі з крикету сезону 2024 року через аналіз застосування методу випадкового лісу

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Реферат. Стаття: 6 с., 1 табл., 4 рис., 26 джерел.

Історія питання. Випадковий ліс (англ. "Random Forest") — популярний алгоритм машинного навчання, який використовується для задач класифікації та регресії. Метою роботи є дослідити застосування методу машинного навчання випадкового лісу для прогнозування шансів команд на перемогу в сезоні 2024 року Індійської прем'єр-ліги (ІПЛ).

Мета дослідження. Шляхом аналізу всебічної статистики гравців, включаючи зіграні матчі, середні показники відбивання та боулінгу, а також активність філдингу, дослідження має на меті з'ясувати фактори, що впливають на успіх команди в крикеті серії T20 ("Twenty20"), і надати практичну інформацію для менеджменту команд, ринків прогнозів та поціновувачів крикету.

Матеріал та методи. У дослідженні взяли участь 10 команд з крикету, які змагалися в сезоні ІПЛ 2024 року. Статистичні дані про гравців та результати матчів за попередні сезони ІПЛ було зібрано та опрацьовано, а відсутні значення отримано за допомогою методу імпутації. Характеристики базувалися на статистиці гравців, включаючи як агреговані показники, так і обчислювані метрики. В якості моделі машинного навчання обрано метод випадкового лісу, який використовується для навчання на основі попередньо оброблених даних, з характеристиками, отриманими на основі статистики гравців – в якості вхідних даних та результатами матчів в якості цільової змінної. Для забезпечення надійного функціонування моделі набір даних було розділено на тренувальний та затверджувальний набори з використанням таких методик, як перехресне затверджування.

Результати. Модель випадкового лісу демонструє суттєву прогностичну ефективність з низькою середньоквадратичною похибкою (СКП) 8,2174, коренем із середньоквадратичної похибки (КСКП) 2,8666 і високим значенням R-квадрату 0,9173, вказуючи на пояснення приблизно 91,73% дисперсії в даних. Команда "Chennai Super Kings" лідирує з прогнозованим відсотком результативності 83,4%, в той час як команди "Punjab Kings" та "Lucknow Super Giants" показують нижчий прогнозований відсоток результативності, що свідчить про наявність потенційних можливостей для її покращення.

Висновки. Це дослідження демонструє ефективність застосування методу машинного навчання випадкового лісу для прогнозування результатів матчів ІПЛ на основі статистики гравців. Дослідження містить цінну інформацію щодо командної динаміки та практичні рекомендації для менеджменту команд і шанувальників крикету. Отримані результати збагачують наше розуміння щодо динаміки матчів ІПЛ, сприяють розвитку аналітики крикету та більшому залученню до спорту, що в кінцевому підсумку підвищує рівень досвіду вболівальників в ІПЛ.

Ключові слова: Індійська прем'єр-ліга, випадковий ліс, машинне навчання, прогнозування результативності команд, аналітика крикету.

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Developing a Core Model for Expected Characteristics of Group Exercise Instructors in Sports Science Students

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Abstract

Background. Sports science experts play a crucial role in providing insights and appropriate recommendations to delineate the desired traits of professional group exercise instructors.

Objectives. The study aimed to investigate the using expert Delphi techniques in developing a core model for expected characteristics of group exercise instructors in sports science students.

Materials and methods. The study involved 18 exercise experts who served as group exercise instructors and lecturers in sports science. Across three questionnaire rounds, the data was assessed using a rating scale, considering Mode (Mo), Median (Mdn), and Interquartile range (IQR).

Results. The experts consistently emphasized the development of the eight core characteristics of group exercise at the highest importance level (Mo = 5, Mdn = 5, IQR = 0). Their focus encompassed areas such as knowledge in anatomy and exercise physiology, proficiency in exercise techniques, understanding of movement, psychological aspects, the role of aerobic dance leadership, and attitude towards group exercise. Additionally, knowledge related to injury prevention and nutrition received respective scores of Mo = 4, Mdn = 4, IQR = 1. Being a group exercise instructor necessitated both physical and mental preparedness.

Conclusions. The desired characteristics for sports science students who will develop themselves to be group exercise leaders have to include a broad range of knowledge to become a personality model, proficiency in all 8 areas, and the ability to effectively teach that lead students to success. And most importantly, the FFITT-VS (Frequency Intensity Training Time Training Type-Volume Progression) principles of teaching should be applied in organizing the group exercise program to ensure appropriateness for each format.

Keywords: characteristic, Delphi technique, group exercise instructors, FFITT-VS principles.

Introduction

Physical activity and exercise across the lifespan can have a profound positive effect on health and well-being (Blair, 2009; Trost et al., 2014). Current recommendations, such as those from the World Health Organization, state that adults should accumulate at least 150 minutes of moderate-intensity (or at least 75 minutes of vigorous-intensity) physical activity per week in bouts of at least 10 minutes. Additionally, it is recommended that children and young people should accumulate at least 60 minutes of moderate to vigorous physical activity each day (WHO, 2021). In Thailand, there has been significant growth in many places, both public and private, with foreign businessmen introducing modern, innovative, fun, challenging, and internationally accepted

exercise styles as part of providing a variety of services to customers. This growth also includes the development and upgrading of the abilities of exercise fitness trainers, ensuring they possess knowledge and expertise in customer relations, as well as proficiency as group exercise instructors in various forms of aerobic exercise. The National Sport Development Plan (2021-2025), with strategic goals geared towards having sports volunteers and exercise leaders ready to help or provide sports and physical activity for the local community (Ministry of Tourism and Sports, 2021). According to the policy of the government agency mentioned above, exercise leaders play a key role in promoting healthy behavior, as their roles and missions are related to changing health behaviors for themselves, their families, and the community.

Currently, there are numerous avenues for individuals to develop themselves as fitness trainers, with some organizations offering training for those without a direct degree in sports science but require certification. To become a proficient leader in exercise, individuals should possess a degree in sports and exercise science, be a physical therapist, or have direct knowledge of health. Historically, Thailand has prioritized this issue, providing guidelines for developing fitness trainers with professional abilities and specialized teaching knowledge, particularly in group exercise instruction (GX), integrated into university courses, especially in sports science professions. This is considered a crucial source for producing personnel and leaders in the exercise field, covering roles as leaders in aerobics and fitness instruction. Therefore, the knowledge imparted by leaders needs to be consistently and properly developed in line with international standards, considering the current increase in the number of group exercise instructors. Currently, the format of aerobic dance has evolved with diverse teaching methods, making exercise activities more engaging. Therefore, it is crucial to consider and apply the fundamental principles of aerobic dance training, which are highly beneficial for development and health promotion. Consequently, instructors should integrate these principles into the design of exercise formats to achieve the objectives of aerobic dance. This involves utilizing the "FFITT" principles (Fun, Frequency, Intensity, Time, Type) (AFFA, 2022). Leaders in aerobic dance must comprehend factors related to different forms of physical movement, utilizing principles and theories of anatomical kinesiology and mechanical kinesiology to design movements that ensure safety in activities. Once understanding the mechanisms of joint function or body movement, these can be effectively introduced into practical learning styles. Good exercise leaders should convey knowledge in exercise according to the principles of exercise (ACE, 2007). However, it has been observed that some aerobic dance leaders in the community studied from videotapes purchased and learned on their own, without a direct degree in sports science. This poses an important factor that may lead to oversight in the teaching process and safety during exercise (Pinitniyom, 2007). This raises the question of what the quality and characteristics of an aerobic leader should be and whether exercisers can derive benefits if the aerobic leader possesses incorrect knowledge.

A variety of fitness professionals play a key role in providing concepts and practices to determine the desirable qualities of a professional group exercise instructor. The Delphi technique is a method for collecting opinions on a particular topic, based on the premise that 'pooled intelligence' enhances individual judgment and captures the collective opinion of experts (Jones et al., 2000; Murry & Hammons, 1995). There are three types of Delphi: conventional, real-time, and policy. The conventional Delphi is the classical forum for the prioritization of facts, involving a questionnaire sent out to a group of experts. A second questionnaire, based on the results of the first, refines and defines the facts or proposals, gauging their accuracy or support from participants (Mariet et al., 2005). The conventional Delphi uses a series of questionnaires to aggregate expert opinions anonymously, taking place over a series of 'rounds.' Communication can occur by post or electronic exchange (Jones et al., 1992). The optimal number of rounds appears to be 2 or 3; however, some Delphi techniques may continue rounds until consensus is achieved or until the last rounds show no significant difference (Graham et al., 2003; Von der Gracht, 2012). As a research process, each Delphi category shares the same overall structure in terms of group communication, anonymity, iteration, and central tendency (Nick & Barry, 2008; Trevelyan & Robinson, 2015).

Defining the right attributes for Group Exercise (GX) can positively impact the development of knowledge and abilities in the professional skills of sports science students. Previous studies have discussed indicators to establish professional competency for elderly exercise instructors (Lan et al., 2016), providing a useful guideline that underscores the importance of developing the characteristics of sports science students to become professionally competent exercise leaders. This aspect has not been studied at the university level in Thailand before. Therefore, various aspects of knowledge must be guided by experts whose knowledge and experience are grounded in the principles of exercise leadership. The researchers recognized the importance of developing desirable attributes for GX using the Delphi method. The Delphi technique, integrating knowledge with experts to determine desirable attributes and incorporating information obtained from the study, serves as a core model for developing sports science students on the verge of becoming future professional group exercise instructors.

Materials and Methods

Study Participants

The participants in this study consisted of 18 qualified individuals with experience in the sports science profession and sports medicine. They were selected using a purposive selection method and divided into three groups: 2 group exercise instructors certified by Les Mills (the copyright owner of group exercise classes), 12 university lecturers who were experts in sports science and exercise, holding a master's degree or higher, and having at least 5 years of teaching experience, and 4 sports medicine professionals in private hospitals who held a bachelor's degree or higher and had at least 5 years of experience in their positions. The participants signed the consent document to participate in the research. The researchers have no conflicts of interest, accurately represent information, and adhere to research ethics in both human and animal subjects. The research

was approved and supervised by the Ethics Committee in Human Research at Loei Rajabhat University, Thailand, project number H 012/2567.

Study Organization

The researcher introduced personal information, explained the research objectives, and provided a brief description of the use of the Delphi Technique. A three-round questionnaire was employed for the research using the Delphi technique. Round 1 question utilized open-ended inquiries to generate answers that would formulate questions for the 2nd and 3rd rounds of the process. The data were analyzed using a rating scale. Experts could express their opinions to indicate agreement or disagreement with each question at the end of the questionnaire, and they were also encouraged to provide suggestions. The answers were then investigated for Mode (Mo), Median (Mdn), and Interquartile Range (IQR). In the final stage, experts could determine whether to modify or confirm their answers (Fig. 1).

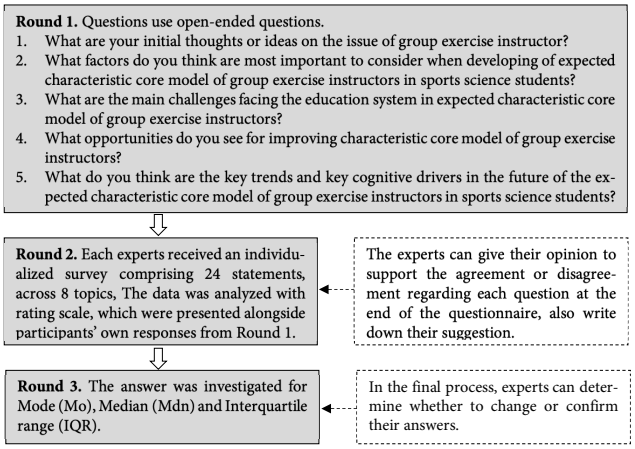

Fig. 1. Flow diagram illustrating the three survey rounds of the Delphi study

Statistical Analysis

The responses of the Delphi technique panelists were analyzed using descriptive statistics. Central tendency statistical analysis was conducted to analyze the data, determining the level of agreement as a percentage. A pre-established measure of consensus was set at 80%. The experts answered the questionnaire and freely expressed their opinions about the questions. When there were no suggested changes in the answers, it indicated that the data had high reliability.

To establish a consensus of opinions, qualification requirements include a median greater than or equal to 4.00 or higher and an interquartile range less than or equal to 1.50, indicating consistency or alignment in the same direction. Once the data were complete, the researcher summarized

Table 1. Removed statements

Component of Characteristics	Statement	% of agreement	Outcome	Selected comments
1	Knowledge of Anatomy and Physiology for exercise	87.75%	Removed following Round 2	To design an exercise program tailored to the activity, gender, and age, sports scientists need to possess understanding in anatomical and physiological principles.
2	Knowledge of exercise	85.12%	Removed following Round 2	Group fitness instructors should possess a variety of teaching skills but must also be attentive to safety during exercise.
3	Knowledge of motions in exercise	82.25%	Removed following Round 2	Can be a teaching model and can skillfully explain the method.
4	Knowledge for preventing injury from exercise	78.47%	Removed following Round 3	Sports scientists need to possess the ability to administer appropriate first aid and adhere to life-saving principles.
5	Knowledge of psychology in exercise	82.54%	Removed following Round 2	There exists a remedy for immediate issues and the capability to foster an environment that facilitates enjoyable instruction through language, emotions, and physical activity.
6	Knowledge of nutrition	77.52%	Removed following Round 3	Sports scientists need to comprehend the ethical use of stimulants, including steroids or misuse, which can result in enduring negative health effects.
7	Knowledge of aerobic dance leadership	85.43%	Removed following Round 2	Possess knowledge of instructional abilities and the presentation and elucidation of techniques.
8	Attitude toward being group exercise instructor	88.71%	Removed following Round 2	Exercise leaders ought to convey information in a clear and comprehensible manner, ensuring brevity and employing a positive and constructive communication style.

Table 2. Responses to statements included in five scale which sought agreed approaches

5 rating scale questionnaires		Median Interpretation	
Rating scale	**Meaning**	**Median**	**Interpretation**
1	Lowest possibility or lowest level of agreement	Lest than 1.50	The statement is mostly impossible or the experts strongly disagree with that statement.
2	Low possibility or low level of agreement	1.50-2.49	The statement is slightly possible or the experts disagree agree with that statement.
3	Not sure	2.50-3.49	The statement is doubtful or the experts slightly agree with the statement.
4	High possibility or high level of agreement	3.49-4.49	The statement is highly possible or the experts mostly agree with the statement.
5	Highest possibility or highest level of agreement	More than 4.50	The statement is possible most or the experts agree the most with the statement.

the information obtained from the analysis of the answers to the three rounds of questionnaires, using the data to design desirable characteristics for group exercise leaders.

Results

Out of the 18 experts surveyed in the field of group exercise instructors (male: 11, female: 7), 1 male and 1 female (5.5%) had a master's degree, with 3 males and 3 females (16.6%). Additionally, 10 experts held a doctorate degree, consisting of 6 males and 4 females (33.3% and 22.2%, respectively). Around 75% of these experts have been researching aerobic dance for over 10 years. Furthermore, approximately 50% of them have worked as group exercise instructors for at least 9 years, and 47.65% have experience as aerobic dance leaders for at least 5 years.

Table 3. Demographic characteristics of Delphi participants

Experts	(n=18)	
Gender	Male (11)	Female (7)
Mean age in years (SD)	42.5 (8.5)	38.6 (6.6)
Education (Number; %)		
Doctoral degree	6 (33.3%)	4 (22.2%)
Master degree	3 (16.6%)	3 (16.6%)
Bachelor degree	1 (5.5%)	1 (5.5%)
Current role (Number; %)		
Professor	–	–
Associate Professor	3 (16.6%)	2 (11.1%)
Assistance Professor	5 (27.7%)	3 (16.6%)
Lecturer	2 (11.1%)	1 (5.5%)
Working in the field	1 (5.5%)	1 (5.5%)
Years working in the field (SD)		
Having research works related in aerobic dance	14 (4.7)	12 (3.3)
With experience as a group exercise instructor	11 (2.8)	10 (2.4)
With experience as an aerobic dance leader	8 (1.8)	8 (1.8)

It was found that in round 3, 16 experts did not change their answers, approximately 90.62%. Meanwhile, 2 experts changed their answers in round 2, approximately 9.37%. If the change rate is lower than 20%, the next round of the questionnaire can be canceled (Murry & Hammons, 1995). A statement from the corresponding luminary ideas on quartile range and the difference between the median and baseline is summarized as a point of opinion of the luminaries in defining desirable attributes for fitness leaders. A section of opinions of luminaries that are important on certain issues. If it is useful, the researcher will discuss the results to make the study data more qualitative. The consistency summary shows that the qualified person has the concept of defining the desirable characteristics of an exercise leader to be up-to-date and skilled in all professional knowledge of 8 topic areas, as shown in Table 4.

The experts focused on knowledge in each area with Mode (Mo) = 5, Median (Mdn) = 5, and Interquartile Range (IQR) = 0. The highest levels were knowledge of anatomy and physiology of exercise, knowledge of exercise, knowledge of motion in exercise, knowledge of psychology in exercise, knowledge of aerobic dance leadership, and attitude toward Group Exercise (GX). Additionally, in the highest knowledge areas, Mo = 4, Mdn = 4, IQR = 1, were knowledge for preventing injury in exercise and knowledge of nutrition.

Discussion

Being an exercise instructor requires knowledge in various areas and the ability to convey the principles of exercise accurately and safely. The researcher was supported by 18 experts using the Delphi technique to gather opinions based on the experts' body of knowledge. It was found that with 17 experts or more, the error rate in the questionnaire process may be reduced to 0.02 (Macmillan, 1971). Therefore, the credibility of the information obtained depends on the skill and experience of experts who have knowledge and expertise in specific areas.

In this research, it was found that most of the experts were knowledgeable and experienced in being leaders in exercise/health and group exercise instruction (GX) for 10 years or more. This information is valuable for developing the expected characteristics of the model for group exercise instructors from this research study. The important topic

Table 4. Mode, Median and Interquartile ranks of the experts' opinion toward 8 areas of knowledge

No	Topic areas	Round 2			Round 3			Level of importance
		Mo	Mdn	IQR	Mo	Mdn	IQR	
1	Knowledge of Anatomy and Physiology for exercise	4	4	1	5	5	0	Strong agree
2	Knowledge of exercise	5	5	0	5	5	0	Strong agree
3	Knowledge of motions in exercise	5	4	0.8	5	5	0	Strong agree
4	Knowledge for preventing injury from exercise	4	5	0	4	4	1	Strong
5	Knowledge of psychology in exercise	4	4	1	5	5	0	Strong agree
6	Knowledge of nutrition	4	4	0.8	4	4	1	Strong
7	Knowledge of aerobic dance leadership	5	4	1	5	5	0	Strong agree
8	Attitude toward being group exercise instructor	5	5	0	5	5	0	Strong agree

Mode = Mo, Median = Mdn, Interquartile range = IQR

areas consisted of 8, as follows: First, the knowledge of anatomy and physiology of exercise. Most experts agreed that understanding anatomy and physiology is fundamental to exercise. Therefore, GX should have knowledge of the structural position of the body and the functions of various systems that affect the body, both at rest and during exercise. GX should be able to understand and explain the changes that occur to ensure safety and prevent dangers (Bryant et al., 2011).

The second is knowledge of exercise. Mostly, experts focused on this issue since GX must understand the principles of exercise for maximum benefit and safety while exercising. Therefore, the experts' opinions consistently emphasize that exercise knowledge has the highest level of agreement. Additionally, the content emphasized by the experts is the fundamental correct postures of exercise and safe exercise program management. Exercise leaders should understand each exercise activity pattern to support and promote effective and sustained exercise (Wanke et al., 2021; Haenel et al., 2021).

The third is movement or motion in exercise. The experts scored this aspect as the highest level of importance (Mo = 5, Mdn = 5, IQR = 0) in terms of muscles and joints mechanisms that affect the efficiency of movement. Therefore, it was proposed that GX should have good motor skills and the correct form of movement according to the mechanics of the body. GX should also transmit the method and the key principles in moving the body properly and safely because group exercise classes involve constant movement in various forms and directions. Correct skill and the performance of appropriate movements affect the ability to control movements safely (Li et al., 2022).

The fourth is knowledge for preventing injuries from exercise. Intensity and speed of movements are important factors contributing to long-term acute and chronic injury problems (Jacobs et al., 2012). Group exercise instructors or aerobic dance leaders should have knowledge and practices in preventing injuries and accidents (Mo = 4, Mdn = 4, IQR = 1), with a focus on locations and equipment that may cause harm while exercising and how to provide first aid. Exercise leaders should have the knowledge to provide advice in order to prevent injuries, assess initial injuries, and treat injuries that occur. Exercise leaders check the availability of venues, shoes, and exercise equipment, as well as describe the factors that may cause injury to enhance the exercise as effectively as possible (Bowerman et al., 2015; Storm et al., 2018).

The fifth topic is knowledge of exercise psychology, focusing on how to persuade others to join dance classes regularly. The experts also suggested that aerobic dance leaders need to strongly motivate dancers to feel the fun of exercising and avoid getting bored with the dance class atmosphere. Consequently, this area was rated with the highest level of importance (Mo = 5, Mdn = 5, IQR = 0). There were also mentions regarding the importance of the good personality of GX that needs to be developed to attract the audience to dance. Therefore, group exercise instructors must be mentally prepared with teaching psychology, an ability to entertain in the class to make it fun and challenging, verbally motivate, and include each participant equally (Marcus & Lewis, 2003).

The sixth topic is knowledge of nutrition (Mo = 4, Mdn = 4, IQR = 1). The experts suggested that it is necessary to know some topics regarding nutrition, such as guidelines for a proper diet program. However, exercise leaders need knowledge and skills that can provide advice on healthy nutrition and nutrition for enhancing physical fitness. They can give advice to service users who are questioning and want to lose weight. Therefore, exercise leaders should have guidelines and useful recommendations for choosing the right diet along with various forms of exercise (Benardot, 2007).

The seventh is knowledge of the group exercise instructor. The experts scored the importance of it at the highest level (Mo = 5, Mdn = 5, IQR = 0). It is significantly suggested that exercise leaders must have a good personality, dress appropriately to lead the dance, select suitable songs for teaching activities, create a proper procedure for teaching dance, and select appropriate dancing postures that fit well with the participants. Exercise leaders should also avoid those dancing postures that may be too dangerous to perform. The dance leader must be able to correct the dancer's incorrect movement posture until it can be safely followed. As the saying goes, "Those who are going to lead others are not only qualified with the expected physical qualities and personal-

ity of a leader because characteristics of leaders are related or compatible with the activities and goals of followers" (Stogdill, 1948). In this regard, experts focused on using a variety of techniques to apply dance teaching activities that are modern, innovative, and challenging. During class, dance leaders should greet participants by smiling or making eye contact, walk thoroughly, and look widely at all participants while leading the dance, and appreciate everyone appropriately. Before finishing, use techniques to say goodbye and thank all participants after completing every class.

Finally, the last topic is the attitude toward being a group exercise instructor. The attitude toward being a GX or instructor was scored by the experts at the highest level of importance (Mo = 5, Mdn = 5, IQR = 0). Being a GX requires both physical and mental readiness. Group exercise instructors should be able to create interesting teachings, always improve their own abilities, and love their own responsibilities. The researcher recognizes the importance of GX properties in developing the potential of sports science students in leadership. Success as a group exercise instructor requires a positive attitude and sincere self-respect, along with respect for other professional peers.

This study indicates that building competency in the characteristics of group exercise leaders should involve specific learning approaches. In the past, there may have been issues with the quality and capability of exercise trainers working in fitness facilities across various locations. Some individuals may lack the expertise to design exercise programs. As reported by Ecclestone and Jones in 2004, the quality of a fitness trainer should be someone who undergoes a standardized learning process and holds certification. Because the role and duties of an exercise instructor require an understanding of the principles of exercise steps, including safety while exercising, especially among the elderly. For success in exercise, adherence to the FFITT principles is essential. However, from the perspective of current GX instructors, there's a need to create diversity in teaching to challenge abilities while also considering the risk of injury and safety. Thus, researchers recognize that both aspects are crucial in organizing GX programs for successful and safe teaching practices. Therefore, they propose modern principles of GX, specifically FFITT-VS, where Variety and Safety principles are highly beneficial for imparting knowledge effectively and safely to both instructors and learners. This ensures that exercise sessions are efficient and learners genuinely benefit from the training. However, in Thailand, the development of training courses for fitness trainers is becoming widespread in both public and private agencies. The results of this research will serve as an indicator certified at the university level and used in teaching sports and exercise science students to develop their potential as exercise trainers, including training future fitness trainer experts.

Conclusions

This research shows that the advice given by the experts is beneficial for the development of the expected characteristics core model of a group exercise instructor in sports science students. In terms of the body of knowledge, it can be implemented for teaching and learning, as well as serving as a guideline to develop sport scientists, including group exercise instructors who need to be qualified with all 8 expected characteristics, being knowledgeable and skillful to perform properly according to the correct procedure. Additionally, being a person who is able to be a role model for others and having good morals and ethics.

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Conflict of interest

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Розробка базової моделі для формування очікуваних характеристик інструкторів з групових фізичних вправ при підготовці студентів спортивних дисциплін

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 4 табл., 1 рис., 28 джерел.

Історія питання. Фахівці зі спортивних дисциплін відіграють вирішальну роль у наданні інформації та відповідних рекомендацій щодо визначення бажаних якостей професійних інструкторів із проведення групових занять з фізичних вправ.

Мета дослідження. Метою роботи було дослідити застосування методів експертних оцінок Дельфі при розробці базової моделі очікуваних характеристик інструкторів з групових фізичних вправ при підготовці студентів спортивного профілю.

Матеріали та методи. У дослідженні взяли участь 18 фахівців у галузі фізичних тренувань, які працювали інструкторами з групових фізичних вправ та викладачами спортивних дисциплін. Впродовж трьох етапів анкетування дані оцінювали за рейтинговою шкалою, враховуючи моду (Mo), медіану (Mdn) та інтерквартильний розмах (IQR).

Результати. Експерти постійно акцентували увагу на розробці восьми основних характеристик групових вправ на найвищому рівні значущості (Mo = 5, Mdn = 5, IQR = 0). В центрі їхньої уваги були такі сфери, як знання анатомії та фізіології фізичних вправ, майстерність техніки виконання фізичних вправ, розуміння рухів, психологічні аспекти, роль лідерства в аеробних танцях і ставлення до проведення групових фізичних вправ. Крім того, знання, пов'язані з профілактикою травм і харчуванням, отримали відповідні бали Mo = 4, Mdn = 4, IQR = 1. Робота інструктора з групових фізичних вправ вимагала як фізичної, так і психічної підготовки.

Висновки. До бажаних характеристик студентів спортивних дисциплін, які прагнуть стати лідерами групових фізичних тренувань, слід віднести широкий спектр знань, які дозволять їм сформувати необхідну модель особистості, володіння майстерністю у всіх 8 сферах, а також здатність до ефективного навчання, що спрямовує студентів на досягнення успішних результатів. Та найголовніше полягає в тому, що принципи навчання FFITT-VS (Frequency Intensity Training Time Training Type-Volume Progression — ключові компоненти тренування, що визначають частоту, інтенсивність, тип та час виконання вправ у відповідному обсязі та прогресії) слід застосовувати в процесі організації програми групових фізичних вправ, з метою забезпечення доцільності для кожного формату тренування.

Ключові слова: характеристика, метод Дельфі, інструктори з проведення групових фізичних вправ, FFITT-VS принципи.

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Original scientific article

The Effects of Resistance Training Interventions on Weight, Body Mass Index, Body Fat Percentage, and Flexibility in College Students: A Comparison Between Sports and Non-Sports Students

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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. Resistance training is an effective form of exercise that promotes healthy body weight regulation and enhances flexibility. However, discrepancies exist regarding the varying impacts of resistance training based on individuals' training status across different fitness components, such as body composition and flexibility.

Objectives. The primary objective of this study is to assess whether there are significant differences in the outcomes of resistance training responses between trained and untrained groups concerning body composition and flexibility.

Materials and methods. This experimental resistance training study involved 60 male students (age = 20.83 ± 0.85 years old) from the same university. The participants were divided into two groups based on their training status: a trained group (S; n = 30) and an untrained group (NS; n = 30). Both groups underwent an identical training regimen, consisting of three sessions per week over a total of four weeks or 12 training sessions.

Results. Significant differences were observed in the paired sample T-test analysis between pre-test and post-test results in the untrained group for body weight ($t_{(29)}$ = 7.940, p < 0.001, d = 1.45), body mass index ($t_{(29)}$ = 7.579, p < 0.001, d = 1.38), body fat percentage ($t_{(29)}$ = 9.733, p < 0.001, d = 1.77), and sit-and-reach flexibility ($t_{(29)}$ = -7.714, p < 0.001, d = -1.40). Similarly, the trained group showed significant changes in body weight ($t_{(29)}$ = 2.644, p = 0.013, d = 0.483), body fat ($t_{(29)}$ = 2.561, p = 0.016, d = 0.351), and flexibility ($t_{(29)}$ = -2.543, p = 0.017, d = 0.351), while no substantial difference was found in body mass index ($t_{(29)}$ = 1.925, p = 0.064, d = -0.464).

Conclusion. The study found that using resistance training protocols targeting weight reduction with 60-70% of 1 Repetition Maximum (RM) over a one-month intervention period, without stringent calorie restriction, significantly decreased weight and BMI while enhancing flexibility. Notably, regardless of training status disparities, the untrained group demonstrated more expressed improvements compared to the trained group, indicating the influence of training status on response variations to training stimuli.

Keywords: resistance training, body composition, flexibility, training status.

Introduction

In 2022, global obesity rates have surged dramatically, surpassing triple the figures recorded in 1975 (Di Cesare et al., 2016). Presently, more than 650 million adults, 340 million teenagers, and 39 million children worldwide are grappling with obesity (World Health Organization, 2021). with projections indicating a continual rise in these numbers annually. According to forecasts from the World Obesity Federation, the prevalence of obesity among children and adolescents is anticipated to soar to 206 million individuals by 2025 and further to 254 million by 2030 (Lobstein & Brinsden, 2019). This issue holds significant global importance due to the strong correlation between adolescent obesity and the heightened risk of obesity-related complications and premature mortality in adulthood (Nicolucci & Maffeis, 2022). Moreover, obesity is linked to an array of health concerns, including cardiovascular diseases (Powell-Wiley et al., 2021), diabetes type 2 (Al-Talabany et al., 2018), cancer (Pati, Irfan, Jameel, Ahmed,

& Shahid, 2023), osteoarthritis (Nedunchezhiyan et al., 2022), respiratory issues (Cortes-Telles, Ortiz-Farias, Pou-Aguilar, Almeida-de-la-Cruz, & Perez-Padilla, 2021), endocrine (Ylli, Sidhu, Parikh, & Burman, 2022), depression (Fu et al., 2023), and reduced quality of life (Stephenson, Smith, Kearns, Haywood, & Bissell, 2021). Hence, urgent measures are imperative to curb the escalating growth rate of overweight or obese adolescents globally.

Flexibility, defined as the capacity to move throughout the full range of motion (ROM) at joints (Afonso, Olivares-Jabalera, & Andrade, 2021), offers a plethora of health advantages that contribute to enhancing daily life quality by averting injuries, back pain, and balance issues (Pate, Oria, & Pillsbury, 2012; Pfeifer, Ross, Weber, Sui, & Blair, 2022). Extensive research indicates that body weight factors can significantly impact flexibility levels. Studies by Pate, Oria, & Pillsbury (2012) highlight that rising obesity rates among adolescents lead to decreased flexibility and overall fitness, consequently impairing postural control and triggering various musculoskeletal health issues. Maintaining a healthy weight and optimal flexibility is imperative for overall well-being. Encouraging the cultivation of these attributes among teenagers can be achieved through engaging in resistance training activities.

Resistance training is recognized for its remarkable effects on the body's metabolic system (Thyfault & Bergouignan, 2020), body weight management (Thyfault & Bergouignan, 2020; Wewege et al., 2022), and overall physical and mental well-being (Gordon et al., 2018; Thyfault & Bergouignan, 2020), consequently enhancing health-related quality of life (Bampton, Johnson, & Vallance, 2015). Furthermore, resistance training is acknowledged for its role in enhancing flexibility by elongating muscle fibers (Blazevich et al., 2014), reducing stiffness in tendons and muscles (Pate et al., 2012), and enhancing the effectiveness of the stretch-shortening cycle (Afonso, Ramirez-Campillo, et al., 2021; Kubo, Ishigaki, & Ikebukuro, 2017). Despite these benefits, research focusing on the impact of resistance training on flexibility remains limited compared to studies on its effects on strength, speed, and power. Given the outstanding advantages associated with resistance training, it comes as no surprise that this form of exercise has gained popularity across diverse age groups, backgrounds, and societal demographics.

While resistance training offers a range of benefits, its primary purpose is to facilitate muscle adaptation (Krzysztofik, Wilk, Wojdała, & Gołaś, 2019). Properly executed resistance training can optimize the adaptation of the musculoskeletal system, leading to enhanced strength in muscles, bones, joints, and tendons (Brumitt & Cuddeford, 2015). Moreover, the outcomes of resistance training adaptation are known to be diverse, influenced by factors such as the type and methodology of training, as well as the intricate interplay of complex training routines, alongside individual differences in age, genetics, and gender (Hughes, Ellefsen, & Baar, 2018). Additionally, various other elements, including one's training status, play a significant role in determining the results of adaptation from resistance training (Hughes et al., 2018).

Numerous studies have highlighted the variability in adaptation outcomes following resistance training, attributing this diversity to an individual's capacity to respond to training stimuli, commonly referred to as their training status. Wetmore et al. (2020) emphasized that trained individuals often require more intense training to achieve notable muscle adaptations compared to their untrained counterparts. Conversely, untrained individuals exhibit heightened responsiveness to training stimuli, enabling them to undergo more substantial adaptations. This phenomenon, as elucidated by Kraemer & Ratamess (2004), is known as the ceiling theory, now popularly recognized as the "newbie gain" trend. This trend suggests that untrained individuals have the potential to experience more pronounced adaptations across various desired outcomes.

Existing research indicates a scarcity of direct comparisons regarding resistance training adaptations based on training status, particularly in experimental studies focusing on weight loss and enhanced flexibility. Therefore, the primary objective of this study is to investigate the impact of training status on the outcomes of resistance training among both untrained and trained groups, focusing on sports students and non-sports students lacking training experience. The findings from this research aim to shed light on prevailing trends and have the potential to inform strategies for promoting health and fitness effectively.

Materials and Methods

Study Participants

The study sample comprised 30 Non-Sports College Students (NS) and 30 Sports College Students (S), aged 21.03 ± 0.89 years and 20.63 ± 0.76 years, respectively. Participants were randomly selected from Yogyakarta State University and voluntarily agreed to take part until the conclusion of the exercise intervention. Inclusion criteria involved students majoring in sports and health sciences, who were categorized as the trained group, and those from non-sports disciplines, who were categorized as the untrained group. Each participant completed a questionnaire derived from the Muscle-Strengthening Exercise Questionnaire (MSEQ) to ascertain their regular exercise habits, particularly engagement in resistance training. The study thus featured two groups: NS (untrained) and S (trained). Body composition and flexibility data (pre-post-test) were collected for both groups to assess changes before and after the resistance training intervention, enabling the evaluation of intervention efficacy.

Experimental Design

This research implemented a resistance training intervention spanning 12 sessions, each held three times a week for 1 to 1.5 hours, resulting in a total intervention period of one month. The primary objective was to investigate the impact of resistance training on body composition metrics (body weight, body mass index, and body fat percentage) and flexibility among both trained and untrained groups. Furthermore, the study aimed to identify which group, between the trained and untrained groups, demonstrated more significant adaptations in body composition and flexibility.

The intervention provided to all research participants aimed to facilitate weight loss through the circuit training method. Both the Standard (S) and Non-Standard (NS) groups adhered to a standardized training regimen,

maintaining consistent sets, rest periods, and the number of exercises, with the only variation being the intensity levels utilized. Throughout the study, the prescribed intensity followed the repetition maximum (RM) principle, with a range set at 60-70% of 1 RM, progressively increasing over the course of the intervention. This approach ensured that the weight was tailored to each participant's individual capabilities. Since we enrolled untrained participants and utilized various resistance training modalities, including gym machines, bodyweight exercises, and free weights, three fitness instructors were engaged to supervise and guide the training program, ensuring participants' safety and injury prevention. Their involvement was voluntary, and the intervention took place at the Health and Sport Center (HSC) Fitness Center, Yogyakarta State University. Details of the training programs administered to the two groups are outlined in Table 1 below.

Table 1. Training sessions distribution in the intervention period

Exercise	Week 1-2*		Week 3-4**	
	Sets	Reps	Sets	Reps
SESSION 1				
Leg Press	2-3	16-20	3-4	12-15
Chest Press	2-3	16-20	3-4	12-15
Pulley	2-3	16-20	3-4	12-15
Shoulder Press	2-3	16-20	3-4	12-15
Total Abdominal	2-3	16-20	3-4	12-15
Lower Back	2-3	16-20	3-4	12-15
Triceps Pushdown	2-3	16-20	3-4	12-15
Arms Curl	2-3	16-20	3-4	12-15
SESSION 2				
Goblet Squat	2-3	16-20	3-4	12-15
Reverse Lunges	2-3	16-20	3-4	12-15
Barbell Romanian Deadlift	2-3	16-20	3-4	12-15
Bench Press	2-3	16-20	3-4	12-15
Barbell Bent-Over Row	2-3	16-20	3-4	12-15
Barbell Overhead Press	2-3	16-20	3-4	12-15
Diagonal Chop	2-3	16-20	3-4	12-15
Kettle Bell Swing	2-3	16-20	3-4	12-15
SESSION 3				
Prisoner Squat Jump	2-3	16-20	3-4	12-15
Dumbbell Bench Step-Up	2-3	16-20	3-4	12-15
Chest Fly	2-3	16-20	3-4	12-15
Machine Lat Pull-down	2-3	16-20	3-4	12-15
Upright Row	2-3	16-20	3-4	12-15
Crunch Coaster	2-3	16-20	3-4	12-15
Biceps Curl	2-3	16-20	3-4	12-15
Triceps Pushdown	2-3	16-20	3-4	12-15

*) Reps according to 60-65% of 1 RM; Rest 2-3 minute between round/circuit; rhyme. Contraction: smooth-fast.
**) Reps according to 65%-70% of 1 RM; Rest 1-2 minute between round/circuit

Testing Procedure

The measurement sessions for each group took place simultaneously at the Fitness Center of HSC. Participants from both groups underwent measurements for body composition and flexibility at the commencement and conclusion of the exercise intervention (pre-post-test). The specifics of the body composition and flexibility measurements are elaborated below.

Body Composition

Body composition measurements were conducted by gathering data on body weight, BMI, and body fat percentage through the Bioelectric Impedance Analysis (BIA) method. BIA is a technique that indirectly measures total body fat percentage by using a low electric current, leveraging the conductive properties of body tissues. This method is commonly employed in health research, clinics, and fitness centers. In this study, BIA measurements were obtained using the Omron Karada Scan tool. Prior to the measurements, participants were advised to wear comfortable and lightweight clothing. The categorization of body fat percentage for individuals aged 20-39 was based on the norms established by Gallagher et al., (2000). The BMI standards applied in this research correspond to the Asia Pacific population BMI guidelines set by the World Health Organisation (2000).

Flexibility

Flexibility measurements were conducted using a sit-and-reach assessment method with the assistance of a sit-and-reach box. Participants were instructed to wear casual or sports attire and remove their footwear before the measurements. They were then guided to sit on the floor with legs extended forward, ensuring the soles of their feet were in contact with the sit-and-reach box. The tester maintained the participants' feet on the floor by holding their knees. Participants placed their hands together with palms facing downward while seated. After taking a deep breath, they exhaled while reaching as far forward as possible along the measurement line on the box. The sit-and-reach test was performed twice with a brief rest in between. The best result from both trials, based on the furthest reach in centimeters, was selected for analysis. These results were compared against Fukuda's (2019) standards to determine the flexibility category for each participant in the study.

Statistical analysis

In this research, the data analysis involved several key stages: descriptive statistical tests, normality test, paired sample t-test, and Cohen's d effect size test.

Descriptive statistical tests included calculations for mean, standard deviation, minimum value, and maximum value. Normality was assessed using the Shapiro-Wilk test, with normal data distribution confirmed if the significance value (p) exceeded 0.05 for both experimental groups. To compare vari-

ables between pre-test and post-test within the groups, the paired sample t-test was applied. A significant difference was indicated by a significance value of less than 0.05 ($p < 0.05$). Following the paired sample t-test results, the analysis proceeded with the Cohen's d test to assess the effect size before and after the intervention. Effect size categories, as per were defined as small (0.2), medium (0.5), and large (0.8). The data analysis was conducted using the SPSS Version 27 software application.

Results

The study results reveal significant changes in all research variables, encompassing both body composition and flexibility measures. These data transformations are evident when comparing the measurement outcomes of the two groups before and after the tests, as illustrated in Tables 2 and 3 below.

Table 2. Statistical Description of Pre-Test Score

Groups	Variables	Mean	Std. Dev	Min	Max
Non-Sport Group (n = 30)	BM	64.97	7.95	49.00	80.00
	BMI	23.10	1.79	19.95	27.61
	BF%	21.12	3.58	13.5	27.00
	S&R	30.66	4.91	21.00	42.00
Sport Group (n = 30)	BM	60.36	6.16	48.00	78.00
	BMI	21.56	1.65	17.85	26.67
	BF%	15.33	3.94	7.00	23.00
	S&R	33.60	3.58	26.00	41.00

Table 3. Statistical Description of Post-Test Score

Groups	Variables	Mean	Std. Dev	Min	Max
Non-Sport Group (n = 30)	BM	26.00	7.95	49.00	80.00
	BMI	23.10	1.79	19.95	27.61
	BF%	21.12	3.58	13.50	27.00
	S&R	30.66	4.91	21.00	42.00
Sport Group (n = 30)	BM	60.36	6.16	48.00	78.00
	BMI	21.56	1.65	17.85	26.67
	BF%	15.33	3.94	7.00	23.00
	S&R	33.60	3.58	26.00	41.00

Table 4. Normality and Homogeneity Test Result

Groups	Variables	Pre-test		Post-test	
		s-w	p	s-w	p
NS	BB	0.966	0.431	0.973	0.637
	BMI	0.957	0.293	0.986	0.949
	BF	0.944	0.116	0.956	0.240
	S&R	0.951	0.185	0.936	0.70
S	BB	0.960	0.315	0.957	0.253
	BMI	0.948	0.147	0.935	0.065
	BF	0.956	0.251	0.936	0.70
	S&R	0.990	0.992	0.989	0.984

Normality and Homogeneity Results

The normality test results using Shapiro-Wilk for all variables in this study show non-significant values ($p > 0.05$). In this case, the obtained results indicate that the data have a normal distribution. Furthermore, detailed normality test results can be viewed in Table 4.

Based on the assumption test requirements for the paired sample t-test, all data that have passed the normality test are considered suitable for the paired sample t-test.

Hypothesis Testing

In general, the results of the paired sample t-test in this study indicate significant differences in the pre- and post-test measurements in groups S and NS. The significance difference of the paired sample t-test in group NS is known to be more significant than in group S for the variables body weight ($t_{(29)} = 7.940$, $p < 0.001$), body mass index ($t_{(29)} = 7.579$, $p < 0.001$), body fat % ($t_{(29)} = 9.733$, $p < 0.001$), and sit and reach ($t_{(29)} = -7.714$, $p < 0.001$). On the other hand, group S is found to have significant differences for the variables body weight ($t_{(29)} = 2.644$, $p = 0.013$), body fat ($t_{(29)} = 2.561$, $p = 0.016$), and sit-and-reach ($t_{(29)} = -2.543$, $p = 0.017$) but is not superior to group NS. The Cohen's d test results also show a larger effect size in the pre- and post-test variables of group NS for body weight ($d = 1.45$), body mass index ($d = 1.38$), body fat % ($d = 1.77$), and sit-and-reach ($d = -1.40$) compared to group S ($d = 0.483$, $d = 0.351$, $d = 0.468$, and $d = -0.464$, respectively) (table 5).

Discussion

This study found a statistically significant difference between groups NS and S for all variables: body weight ($t_{(29)} = 7.940$, $p < 0.001$), BMI ($t_{(29)} = 7.579$, $p < 0.001$), body fat% ($t_{(29)} = 9.733$, $p < 0.001$), and Flexibility ($t_{(29)} = -7.714$, $p < 0.001$). Furthermore, advanced tests to determine the effect size through Cohen's d showed that group NS had better changes with a very large effect size on the impact of resistance training from 64.97 ± 7.95 kg to 62.77 ± 7.36 kg ($d = 1.45$), BMI from 23.10 ± 1.79 to 22.23 ± 1.71 ($d = 1.38$), body fat% from 21.12 ± 3.58% to 18.62 ± 2.72% ($d = 1.77$), and flexibility from 30.66 ± 4.91 cm to 34.71 ± 4.65 cm ($d = -1.40$) compared to group S with results of the impact on weight from 60.36 ± 6.16 kg to 60.04 ± 5.93 kg ($d = 0.483$), BMI from 21.56 ± 1.65 to 21.46 ± 1.58 ($d = 0.351$), body fat% from 15.33 ± 3.93% to 15.01 ± 3.76% ($d = 0.468$), and flexibility from 33.60 ± 3.58 cm to 34.52 ± 3.29 cm ($d = -0.464$).

Table 5. Paired Sample T with Cohen's D Test Results

Variables	Non-Sport Group (n = 30)					Sport Group (n = 30)				
	Pre-Test	Post-Test	t	p	E.S.	Pre-Test	Post-Test	t	p	E.S.
Body Weight (kg)	64.97±7.95	62.77±7.36	7.940	<0.001	1.45	60.36±6.16	60.04±5.93	2.644	0.013	0.483
Body Mass Index (BMI)	23.10±1.79	22.23±1.71	7.579	<0.001	1.38	21.56±1.65	21.46±1.58	1.925	0.064	0.351
Body Fat (%)	21.12±3.58	18.62±2.72	9.733	<0.001	1.77	15.33±3.93	15.01±3.76	2.561	0.016	0.468
Sit and Reach (cm)	30.66±4.91	34.71±4.65	-7.714	<0.001	-1.40	33.60±3.58	34.52±3.29	-2.543	0.017	-0.464

The variable BMI in the pre- and post-tests in group S is the only variable that did not show significant differences in this study. Nevertheless, the changes in group S for the BMI variable tend to decrease as seen from the descriptive test results in Tables 2 and 3 above. Overall, the impact of resistance training on groups NS and S shows significant differences (except for the BMI variable in group S), where group NS outperforms group S. These findings support previous research that training status affects the adaptation results of resistance training or, in this study's context, changes in body composition and flexibility. Furthermore, the information obtained from this study can be used to promote resistance training and motivate students, especially the untrained ones, to participate more in resistance training due to its beneficial effects.

The Effects of Training Status Toward Body Composition

It is well known that besides muscle adaptation, resistance training is effective in helping regulate fat or body composition in various populations (Buskard & Petrella, 2023; Campa et al., 2020; Dias et al., 2015; Ribeiro et al., 2022; Schranz, Tomkinson, & Olds, 2013). Similar to resistance training aimed at muscle adaptation, resistance training aimed at weight loss or regulation can also lead to different adaptation results depending on the interaction of factors such as types, methods, and interactions of the highly complex training regimen, in addition to age differences, genetics, gender, and others (Hughes et al., 2018). According to Ataeinosrat et al. (2022), resistance training using circuit training or interval resistance training methods can significantly reduce weight compared to resistance training using traditional resistance training methods. Meanwhile, the study by Kapsis et al. (2022) shows that there are differences in the impact of weight selection in High-Intensity Functional Training, where training with light weights (30% of 1 RM) is more significant for fat loss compared to moderate weights (70% of 1 RM) in healthy adult populations. Even more simply, resistance training using different modalities such as bodyweight, free-weight, and resistance bands can also affect weight loss adaptation results (Liu et al., 2021). Through this study, resistance training with moderate weights (60-70% of 1 RM) to muscle failure using circuit training methods and a combination of free weight, gym machines, and body weight modalities can significantly reduce weight, BMI, and fat percentage in the student population (young adults) regardless of their training status.

Meanwhile, changes in weight, specifically fat, are caused by the interaction of intake, expenditure, and energy needs in the homeostatic energy system (Reis, Júnior, Zajac, & Oliveira, 2011; Ribeiro et al., 2022). Simply put, the key to success in weight loss is the ability to manage these three factors well to support a reduction in body fat percentage. Therefore, individuals who can limit calorie intake and increase their energy expenditure are more likely to reduce their body fat percentage. Interestingly, this study shows that resistance training to muscle failure with 60-70% of 1 RM alone as one factor of energy expenditure, without strict calorie restriction, can still reduce body fat percentage in both groups.

The findings of this study may be supported by Brunelli et al. (2019), who found that resistance training with low and high weights (30% or 80% of 1 RM) performed to muscle failure results in almost the same total amount of energy expenditure, which can be applied to aid in weight loss. Thus, resistance training can be utilized as one strategy in regulating weight in a healthy manner. However, the study highlights that low-resistance training is more effective in assisting weight loss. This is due to the higher level of energy expenditure during low-resistance training compared to high-resistance training. In addition to this study, various research also supports the findings of this study stating that resistance training is an effective exercise for weight regulation.

In this study, differences in resistance training responses were observed between untrained and trained populations. We acknowledge that without measurements for other supporting variables, the process of connecting why the effects of training status lead to apparent changes in body composition variables becomes challenging to comprehend. Nevertheless, these differences in response to resistance training stimuli, particularly regarding changes in weight, BMI, and body fat percentage between untrained and trained populations can be attributed to various factors such as differences in BMR, the floor-ceiling effect, and sensitivity to training stimulus responses as indicated by available literature sources (Farhana & Rehman, 2021; Souza, Barbalho, & Gentil, 2020). Studies by Poehlman, Melby, and Goran (1991) indicates that the resting metabolic rate in trained populations is higher compared to untrained populations, implying that trained individuals require significantly more energy. As a result, trained populations may exhibit relatively effective regulation of body fat percentage compared to the untrained group. However, despite their lower RMR, untrained populations tend to experience more significant changes, including notable weight loss, possibly due to other factors such as rapid metabolic adaptations or increased sensitivity to training stimuli in this group.

Furthermore, the ceiling effect is a phenomenon in the sports world wherein an individual (or a population sharing the same characteristics) experiences adaptation to the maximum level as a result of the stimulus response from training (Lochbaum et al., 2022; Wetmore et al., 2020). In this case, someone experiencing the ceiling effect will find it difficult to improve their athletic performance to the next level because they have reached a certain peak performance (Behm et al., 2024; Schoenfeld et al., 2019). Regardless of the various factors that can influence the ceiling effect, this phenomenon has been extensively documented and researched in various aspects of athletic performance such as muscle strength and endurance (Hughes et al., 2018; Peterson, Rhea, & Alvar, 2005), hypertrophy (Lopez et al., 2021), VO_2max (Santisteban, Lovering, Halliwill, & Minson, 2022), speed (Behm et al., 2017), power (Moran et al., 2023), and even skill acquisition commonly observed in trained individuals. In relation to this, the significant differences in weight loss, BMI, and body fat percentage between the NS and S groups may be greatly influenced by this effect. Participants in the S group in this study are athletes from various sports disciplines who regularly undergo training sessions focusing on both technical and physical aspects. On the other hand, untrained individuals in this study show low levels of sports participation, especially in resistance training. Given these conditions, it is logical that the untrained group

experienced significant decreases in all body composition variables compared to the trained group.

Meanwhile, although not yet precisely understood, the ceiling effect theory may be associated with the theory of beginner gains. The theory of beginner gains emphasizes the potential of the untrained population to adapt more significantly to training stimuli compared to the trained population (Fyfe & Loenneke, 2018). In this case, untrained individuals exhibit a higher potential for sensitivity to stimuli compared to trained individuals. Some studies suggest that differences exist in strength improvement, muscle size, and overall fitness between trained and untrained individuals, with greater improvements observed in the untrained population. Furthermore, the differing sensitivity to stimuli based on training status may also influence the adaptation outcomes of body composition aspects from resistance training. Trained individuals may require more advanced training methods and/or increased training volume compared to untrained individuals (Wetmore et al., 2020).

The Effects of Training Status Toward Flexibility

Flexibility can be enhanced through various methods such as static stretching, dynamic stretching, PNF, and foam rolling (Kasahara et al., 2023). Recent advancements in scientific literature suggest that resistance training, when performed without incorporating flexibility training, can actually improve flexibility across different populations (Leite et al., 2017). A recent meta-analysis by Afonso et al. (2021) supports the notion that resistance training can enhance flexibility by increasing the range of motion (ROM) in specific joints. This type of resistance training involves utilizing free weights, gym machines, and Pilates. Furthermore, several studies concur that specific resistance training exercises can improve flexibility and joint ROM to a significant extent, comparable to traditional flexibility exercises like static and dynamic stretching (Alizadeh et al., 2023; Behm, Aragão-Santos, Korooshfard, & Anvar, 2023). Additionally, flexibility was observed to increase following resistance training interventions due to factors such as increased muscle fiber length (Blazevich et al., 2014), alterations in tendon-muscle stiffness (Pate et al., 2012), and the effects of the stretch-shortening cycle during exercise (Afonso, Ramirez-Campillo, et al., 2021; Kubo et al., 2017). These findings shed light on why both groups in the study experienced significant improvements in flexibility.

Moreover, research indicates a strong correlation between muscle flexibility, range of motion (ROM), and muscle weakness (Frasson et al., 2020; Pettersson et al., 2019). Studies have demonstrated that weak muscles can lead to a reduction in joint flexibility and ROM, as highlighted by Zeng et al. (2021). While the researchers did not directly measure muscle strength in this study, it is plausible that the enhancements observed in both the NS and S groups could be attributed to gains in muscle strength. The notably greater improvement in flexibility among the untrained group may be attributed to their initial lower muscle strength compared to the trained group. This discrepancy in muscle strength levels between the groups likely influenced how they responded to resistance training in terms of flexibility. Additionally, as per Alizadeh et al. (2023), the trained group started with higher baseline flexibility, potentially limiting further significant gains in flexibility. Conversely, the untrained group, with initially poorer flexibility fitness, benefited from a more pronounced response to the resistance training stimulus, leading to a more substantial increase in flexibility.

Some studies propose that stretch tolerance could play a role in how resistance training affects flexibility gains. Trained individuals often exhibit higher muscle stretch tolerance, possibly due to their regular engagement in resistance training and exercises that stretch muscles to their maximum capacity. Conversely, the untrained group typically shows lower flexibility fitness and poorer stretch tolerance. Resistance training is believed to enhance stretch tolerance, potentially explaining the more substantial increase in flexibility observed in the untrained group compared to the S group.

In summary, variations in responses to resistance training among populations with different training statuses (trained and untrained) could be attributed to the interplay of several intricate factors. While the NS group demonstrated superior adaptation results regarding body composition, the S group also exhibited significant outcomes. This implies that resistance training proved advantageous for both groups. The researcher acknowledges that this study alone is inadequate to comprehensively explain a broad subject, such as the effects of diverse training statuses, given the limitations inherent in this research.

Resistance training response results can vary based on the training program's design, regimen, and methodology. The researchers propose that relying solely on maximum repetitions may not offer sufficient insight into the outcomes of this study. While maximum repetitions can tailor to individual characteristics, a more diverse and intricate training regimen is necessary for comprehensive understanding. Additionally, as this study exclusively focused on a young adult population, its findings may not be universally applicable. Research across different age groups is essential to explore variations in the effects of training status. Drawing from existing literature, this study suggests the presence of mediator variables that influence how training status impacts body composition and flexibility. To delve deeper into these differences, researchers advocate for the inclusion of various variables such as RMR, ceiling effect, training stimuli sensitivity, muscle fascicle length, and muscle stiffness. Furthermore, the limited research on the effects of resistance training on flexibility contrasts with the extensive studies on strength, speed, power, and other variables.

Conclusions

The research findings indicate that resistance training programs aimed at weight loss, utilizing 60-70% of 1 Repetition Maximum (RM) over a one-month intervention period without strict calorie restrictions, can significantly decrease weight and Body Mass Index (BMI) while enhancing flexibility, irrespective of training status differences. Nonetheless, the NS group in this study exhibited greater improvements compared to the S group, suggesting that training status influences how groups respond to training stimuli differently. Therefore, it is hoped that the outcomes of this study can serve as a catalyst to underscore the significance of fitness, body composition, and flexibility, particularly within the student demographic.

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Conflict of interest

The authors declare that they have no conflicts of interest associated with this research, including financial interests, affiliations, or involvement with any organization that might have a stake in the findings presented.

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Вплив інтервенцій з виконання силових тренувань на показники ваги, індексу маси тіла, процентного вмісту жиру в тілі та гнучкості у студентів коледжів: порівняльний аналіз між показниками студентів, які займаються і не займаються спортом

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 5 табл., 59 джерел.

Історія питання. Силові тренування — це ефективна форма фізичних вправ, що сприяє здоровому регулюванню маси тіла та покращує показники гнучкості. Однак існують розбіжності щодо різних факторів впливу силових тренувань залежно від стану тренованості осіб стосовно різних компонентів фізичної форми, таких як композиція тіла та гнучкість.

Мета дослідження. Основна мета цього дослідження полягає в оцінці того, чи існують значні відмінності в результатах реакцій на силові тренування між тренованими та нетренованими групами щодо композиції тіла та гнучкості.

Матеріали та методи. У цьому експериментальному дослідженні з вивчення впливу силового тренування взяли участь 60 студентів чоловічої статі (вік = 20,83 ± 0,85 років) з одного університету. Учасники були розділені на дві групи залежно від їхнього стану тренованості: тренована група (S; n = 30) і нетренована група (NS; n = 30). Обидві групи проходили ідентичний тренувальний режим, що складався з трьох занять на тиждень протягом чотирьох тижнів або 12 тренувань.

Результати. Значні відмінності спостерігалися в аналізі T-коефіцієнту парної вибірки між результатами до і після тесту в нетренованій групі для показників маси тіла ($t_{(29)}$ = 7,940, p < 0,001, d = 1,45), індексу маси тіла ($t_{(29)}$ = 7,579, p < 0,001, d = 1,38), процентного вмісту жиру в тілі ($t_{(29)}$ = 9,733, p < 0,001, d = 1,77) і тесту на гнучність sit-and-reach (спосіб вимірювання загальної гнучкості тіла при згинанні тулуба вперед, сидячи на підлозі з витягнутими вперед руками) ($t_{(29)}$ = -7,714), p < 0,001, d = -1,40). Аналогічним чином, тренована група досліджуваних продемонструвала значні зміни у показниках масі тіла ($t_{(29)}$ = 2,644, p = 0,013, d = 0,483), вмісту жиру в тілі ($t_{(29)}$ = 2,561, p = 0,016, d = 0,351) і гнучкості ($t_{(29)}$ = -2,543, p = 0,017, d = 0,351), тоді як в індексі маси тіла істотної різниці не спостерігалося ($t_{(29)}$ = 1,925, p = 0,064, d = -0,464).

Висновок. В ході дослідження було встановлено, що використання протоколів силових тренувань, спрямованих на зниження ваги з рівнем 60-70% від одного повторення з максимальною вагою (RM) протягом одного місяця інтервенції, без суворого обмеження калорій, сприяло значному зменшенню ваги та IMT, підвищивши показники гнучкості. Слід зазначити, що незалежно від розбіжностей у стані тренованості, нетренована група продемонструвала більш виражене покращення показників порівняно з групою тренованих осіб, що вказує на вплив стану тренованості на варіації реакції відносно тренувальних стимулів.

Ключові слова: силове тренування, композиція тіла, гнучкість, стан тренованості.

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One-Year Post COVID-19 Change in Physical Fitness of Primary School Children and Its Individual-Level Predictors

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Abstract

Objectives. The study aimed to evaluate physical fitness and its dynamics in a year among primary school children aged 7 to 10 years old concerning the child's individual factors (health-related: physical activity, sedentary behaviour; and psychosocial: physical activity enjoyment).

Materials and methods. The study involved a sample consisting of 902 1st-3rd grade students (49% of boys and 51% of girls), who participated in physical fitness testing at baseline and follow-up in a year. Additionally, questionnaire-based data were collected from students and parents. Physical fitness was evaluated by administering eight out of nine tests from a 9-item test battery developed by Fjørtoft et al. (2011). The participants' height and weight were measured using a mechanical stadiometer platform (Seca 274, Hamburg, Germany; TEM50.01%) and a portable electronic scale — a TANITA BC 420 SMA (Tanita Europe BV, Amsterdam, The Netherlands), respectively. Physical activity, sedentary behaviour, participation in sports, physical activity enjoyment were evaluated by children and parents at different time points.

Results. The results indicated that physical fitness had improved from baseline to follow-up, with some exceptions for particular tests and genders. Vigorous physical activity at Time 1 predicted better hand muscle strength (Std β = 0.18) and agility (Std β = -0.12) at Time 2. The findings showed that participation in sports at Time 1 was also predictive of improved agility (Std β = 0.15). Moderate to vigorous physical activity at Time 1 predicted enhanced speed at Time 2 (Std β = -0.16). The motivation for physical activity at Time 2 was found to be related to improvements in agility (Std β = -0.18) and speed (Std β = -0.30), while there was a decline in hand muscle strength (Std β = -0.11). Altogether, predictors were able to significantly explain 10 percent of agility and 13 percent of speed test results.

Conclusions. As children grow and develop, their physical fitness levels tend to change in response to various factors including different physical activity indicators, as well as motivation for engaging in physical activity.

Keywords: physical fitness, primary school children, longitudinal study, motor fitness, musculoskeletal fitness.

Introduction

The year 2020 was marked by the global COVID-19 pandemic followed by confinement and home-schooling for almost a year. The pandemic had an impact on many educational and health as well as health behavior outcomes of schoolchildren including lower physical activity at physical education (PE) lessons during distance learning (Roe et al., 2021), lower levels of physical activity (Caputo & Reichert, 2020), more time spent passively (Roe et al., 2021; Rossi et al., 2021), limited or none participation in after school organized sports (Calcaterra et al., 2022). Meanwhile, physical activity in childhood is reported to have a significant accumulative impact on future health, particularly physical fitness (Telama et al., 2014). Moreover, studies report increased body mass index as a negative consequence of the pandemic (Jarnig et al., 2021; Tsoukos & Bogdanis, 2021) as another health trigger. In Lithuania, schools closed on 16th March 2020 and opened on 15th June 2020. Then, after the incidents of COVID-19 increased dramatically again, schools closed in 14th December 2020. Primary school children returned to school and normal physical education on 15th March 2021. It became crucial to evaluate children's after-pandemic physical fitness, given it is a determinant of future health.

Organizations like the United States Department of Health and Human Services ([USDHHS], 2018) and, the National Center for Chronic Disease Prevention and

Health Promotion (1996) called for regular youth fitness testing. The assessment of physical fitness brings vital information for individual healthcare and public health to improve health (Kolimechkov, 2017; Ortega et al., 2015), especially for primary prevention of cardiovascular disease (Ruiz et al., 2016). Regular monitoring of physical fitness is recommended by The American Heart Association (AHA). Following these recommendations becomes specifically important in times of crisis like COVID-19 when regular education experiences drastic changes and normal PE is not available in many cases.

Physical fitness is defined as a state of good health that allows one to perform daily activities vigorously and also helps to reduce the risk of chronic diseases and premature death (Castro-Piñero et al. 2019). The main components of physical fitness are cardiorespiratory fitness, musculoskeletal fitness, and motor fitness. Physical fitness plays a key role in a child's sustainable growth and developmental process (Zhou et al., 2014). Low physical fitness is an important risk factor for cardiovascular disease, type 2 diabetes, and mortality (Faselis et al., 2012; Kokkinos et al., 2012; Timpka et al., 2014). Low cardiorespiratory fitness is associated with a risk of mental and physical health (Ortega et al., 2008). Although morbidity usually comes to manifestation in midlife, the basis for disease develops progressively over time with some signs appearing as early as childhood (Peralta-Huertas et al., 2008) or adolescence (Högström et al., 2016). Also, higher physical fitness, particularly motor fitness is associated with improved children's cognitive abilities and academic achievements (Batez et al., 2021; London & Castrechini, 2011; Moradi et al., 2019; Ruiz-Ariza et al., 2017) as well as better quality of life in childhood (RedondoTébar et al., 2019).

Before the pandemic, physical fitness in school-aged children was constantly declining from decade to decade (Malina, 2007; Olds, Ridley, & Tomkinson, 2007; Venckunas et al, 2017). Reports on secular trends in physical fitness state that cardiorespiratory fitness which is of utmost importance for heart health declined during the last several decades (Venckunas et al., 2017; Fühner et al., 2021) as well as musculoskeletal fitness (Fühner et al., 2021). Some researchers noticed that 7.3% of the decline in cardiorespiratory fitness over 33 years from 1981 stabilized around 2000. However, this is applied only to cardiorespiratory fitness and serves as a general trend, given it was made by summarizing data from 137 countries, and may vary from country to country (Tomkinson et al., 2017). In Lithuania, cardiorespiratory fitness has declined by as much as 50 percent from year 1992 to 2012 among adolescents (Venckunas et al., 2017). This might be related to the population's increasing and earlier onset of health problems in society, and disease-related costs for the health care system.

The complex etiology of physical fitness among other factors like endogenous factors (genes, gender, and maturity), and exogenous ones like health-related behaviors, with children without overweight or obesity and more physically active and eating healthier are more fit than those obese and lacking appropriate dietary patterns as well as physical activity (Cabanas-Sánchez et al., 2018). Studies of physical fitness among young children mostly investigate the predictive value of the latter for different health and academic outcomes. However, evidence for etiology is scarce for young children. Moreover, there is a lack of longitudinal studies including predictors of current physical fitness from different time points.

Thus, physical fitness is affected by multiple factors, and the effect of each could be compensated or amplified in their interplay. Therefore, studies of separate factors do not tackle this interaction. The most proximal factors according to the Ecological approach are individual (intrapersonal) ones (Sallis et al., 2015). Examining the interplay of these factors and identifying the unique significance of each contributing to improvement of physical fitness of primary school children is of utmost importance and will let identify targets for future interventions. Thus, we hypothesize that physical fitness improves after returning to school and normal life after COVID-19 confinement and improvement is significantly associated with physical activity facors.

According to the statements mentioned above, the research aims to estimate physical fitness and its dynamics in a year among primary school children aged 7 to 10 years in relation to the child's individual factors (health-related: physical activity, sedentary behavior; and psychosocial: physical activity enjoyment).

Materials and Methods

Study Participants

This analysis included a sample consisting of 902 students, who participated at both time points and whose additional data from questionnaires were collected. At Time 1 they were 1st to 3rd grade students and at Time 2, they were 2nd to 4th grade students. For each of the tested students data was obtained from one of their parents them filling the questionnaires. Among students, there were 49% of boys and 51% of girls. The majority of parents consisted of mothers (83.2%). Data included 38.8% 7-years-old, 24.8% 8-years-old, 28.6% 9-years-old, 7.8% 10-years-old children at Time 1, and the respective amount of 8, 9, 10, and 11-years-old students at Time 2.

Study Organization

This study was part of a bigger PhD project (KD-19062. 2019), which aimed to represent national indicators of the physical fitness of primary school students. The initial sample of tested students consisted of 2886 students in primary school grades 1 to 4th. However, questionnaires were delivered to the smaller part of students of the initial sample and their parents or guardians. All children had their physical fitness evaluated. At Time 1 parents filled the questionnaires. At Time 2 students were also provided questionnaires to fill out.

Ethics approval for the research was obtained from the Lithuanian Sports University Ethics Committee (No. SMTEK-52). Research-related information was disseminated through the schools' administrations. Parents or legal guardians provided written informed consent and children for their consent were asked verbally. Physical fitness testing is a part of a yearly physical education curriculum and collected indicators are provided to the Lithuanian Healthcare Ministry. Only students who were allowed to attend physical education classes were tested. During the year between tests, all tested students at their school had three

physical education lessons per week.Indicate methods and the purpose of their use; research procedures and an algorithm for conducting a pedagogical experiment.

Measures

Physical Fitness

Eight out of nine tests from a 9-item test battery developed by Fjørtoft et al. (2011) and described in detail elsewhere (Fjortoft et al., 2011) were used to evaluate muscular, and motor fitness in primary school students. The test battery included the following tests for musculoskeletal fitness: Standing broad jump (explosive strength), Jumping a distance of 7 m with both feet, Jumping a distance of 7 m on 1 foot (both tests indicate leg muscle strength), Throwing a tennis ball with one hand (arm muscle strength), and Pushing a medicine ball with both hands (upper body muscle power). For motor fitness, the students performed a shuttle run of 10X5 m (agility) and Running 20m as fast as possible (speed) (Fjortoft et al., 2011).

Height was measured to the nearest 0.1 cm using a mechanical stadiometer platform (Seca 274, Hamburg, Germany; TEM50.01%). Body mass was measured to the nearest 0.1 kg using a portable electronic scale—a TANITA BC 420 SMA (Tanita Europe BV, Amsterdam, The Netherlands). Body mass index (BMI) was calculated as mass kg/height $(m)^2$. The International cut-off points for body mass index for overweight and obesity were applied by Cole and colleagues (2000) to differentiate between 1) not overweight and 2) overweight or obese children. The children were clothed in underwear and were barefoot while their anthropometric measurements were taken.

Individual Measures

Physical activity and time spent passive (Time 1). Physical activity and time spent passively by primary school-aged children were assessed by their parents filling out a questionnaire developed by Bacardi-Gascón and colleagues (Bacardi-Gascón et al., 2012). We used four questions assessing time spent passively, in light, moderate, and vigorous physical activities (watching television, going to school, time in the yard, in the park, playing games, etc.). Answers to choose from were as follows: 15 minutes, 30 minutes, 45 minutes, 1 hour, and more than 1 hour. We binarized answers on each item into 1 – less than an hour and 2) more than an hour.

Participation in sports (Time 1) was assessed by the question "Does your child participate in any of these activities during the week?". A list of possible activities was provided (karate, gymnastics, soccer, dance, baseball, swimming, etc.). the answers were dichotomized into 1 (Yes) and 2 (No).

Physical activity (Time 2) was measured by asking students themselves two questions: 1) How many times per week do you play active games, and/or do sports until sweat; 2) How much time do you usually spend each time playing active game and/or doing sports on average? The total score of physical activity in hours was calculated by multiplying the number of days per week with minutes per activity ocation and dividing by 60.

Time spent passive (Time 2) was identified by asking students how much time in hours and minutes they spend watching TV, using a computer, doing homework, reading books, playing table games, and playing with or talking on a smartphone. All the numbers were summed up into total minutes spent passively per day.

Physical activity enjoyment (Time 2). The 16-item PACES (Physical Activity Enjoyment Scale; Moore et al., 2009) questionnaire for students was used to assess the enjoyment of being physically active. Answers were provided on a 5-item Likert scale from 1 – "Definitely no" to 5 – "Definitely yes". The sum of all 16 items was used for calculations. The higher the score the higher the motivation to participate in physical activities. The Cronbach alpha of the scale was 0.867.

Statistical Analysis

Descriptive statistics was employed for the evaluation of means, standard deviation for scale variables, and frequencies for categorical or ordinal variables. Student t criteria were used to identify mean differences among two groups and ANOVA – for more than two groups. A pairwise comparison was performed to identify differences in scale variables between the two time points. The series of hierarchical linear regressions were made to evaluate the unique value of independent variables – covariates and groups of predictors – for dependent variables. Statistical software package SPSS 28 was used for calculations. Results were considered statistically significant when the value was <.05.

Results

Firstly, sample characteristics were analyzed and compared in gender and age groups. Results presented in Table 1.

Descriptive statistics in Table 1 show that there are 7 percent of overweight or obese children. A comparison of results between genders and age groups revealed that older children are overweight or obese more often than their younger counterparts. There is no gender-related prevalence of overweight or obesity. Inactivity, light, and vigorous physical activity at Time 1 were similar between genders and among age groups. Boys and those aged 7 and 9 years old engaged in MVPA at Time 1 more often than girls and those aged 8 and 9 years old. At Time 2 boys displayed higher scores on time spent passively than girls. However, inactivity is similar among different ages primary school students. More than eight out of ten children are engaged in extracurricular sports, with boys and older children engaged more often than girls and younger children. Engagement in MVPA in terms of hours spent in MVPA per week constantly increases with age. Physical activity enjoyment remains the same across genders and age groups.

Results in Table 2 reveal that explosive muscle power (Standing broad jump) constantly increases with age in both boys and girls with a higher magnitude in older age for boys. The older the age the higher the difference in Standing broad jump results in comparison with the previous measurement one year before in boys. However, the increase in girls is not that smoothly rising – the gain between 7 and 8 years and 9 and 10 years is higher than between 8 and 9 years. Similarly, in constantly increasing order changes in leg muscle strength are observed performing Jumping on one foot test in girls for

Table 1. Descriptive statistics and comparisons between age groups and gender

Individual factors	Total	Boys	Girls	7/8 years	8/9 years	9/10 years
Gender						
Boys (% (N))	50.7 (263)					
Girls (% (N))	49.1 (254)					
Age (years; Time 1; mean (SD))						
7	24.2					
8	23.9					
9	23.5					
10	23.1					
11	5.3					
BMI (Time 1; mean (SD))						
Normal	93.0	92.5	93.4	90.4	92.7	93.0
overweight, obese	7.0#	7.5	6.6	9.6	7.3	7.0
Sedentary behavior after school (Time 1; %)						
<1 h/day	11.6	9.0	13.8	9.2	11.5	14.7
>1 h/day	88.4	91.0	86.2	90.8	88.5	85.3
Light PA (Time 1; %)						
<1 h/day	48.1	48.1	48.1	50.8	49.3	47.3
>1 h/day	51.9	51.9	51.9	49.2	50.7	52.7
MVPA (Time 1; %)						
<1 h/day	33.3	26.0	39.4	26.9	40.6	34.0
>1 h/day	66.7*#	74.0	60.6	73.1	59.4	66.0
VPA (Time 1; %)						
<3.5 h/week	73.4	72.5	74.1	79.3	79.9	65.9
>3.5 h/week	26.6	27.5	25.9	20.7	23.1	34.1
Sports (Time 1; %)						
Engaged	86.4*#	90.1	82.6	72.5	73.8	85.8
Not engaged	13.6	9.9.	17.4	27.5	26.2	14.2
Sedentary behavior after school (Time 2; min/day; mean (SD))	394 (175)*	433.94 (172.75)	377.35 (174.73)	393.13 (178.27)	419.80 (179.68)	397.54 (164.79)
MVPA (Time 2; h/week)	6.24 (5.03)#	6.81 (5.54)	5.89 (4.99)	5.45 (4.58)	6.22 (5.27)	6.37 (4.96)
PA enjoyment (Time 2)	68.28 (9.63)	68.19 (9.17)	69.35 (9.20)	69.85 (8.82)	68.72 (9.18)	68.42 (8.75)

Note: BMI – body mass index; PA – physical activity; MVPA – moderate to vigorous physical activity; VPA – vigorous physical activity; * - statistically significant (p<.05) difference between genders; # - statistically significant (p<.05) difference among ages.

all age transitions and in boys from 8 to 10 years. Jumping on two feet test results increase from 8 to 10, with a higher magnitude between 8 and 9 in both genders. Hand muscle power and upper body muscle power (Tennis ball and Medicine ball, respectively) increase from year to year except for no significant gain in girls in the transition between 9 and 10 years for the Medicine ball test. Agility results in boys increasing across transitions from 8 to 9 years and from 9 to 10 years. There was no significant gain in one year between 7 and 8 years in boys for agility. In girls, agility increases across all age transitions, the highest increase is between ages 9 and 10 years. The speed significantly increases in boys and girls except for the transition in girls from 8 to 9 years.

Results in Table 3 show that among covariates the initial result on the test on Time 1 and age are the strongest predictors of the results a year after. The higher was initial physical fitness the higher it remains after a year passes by. Boys outperformed girls on explosive muscle power (Standing broad jump) until predictors were added, and hand muscle power (Tennis ball, Medicine ball). Leg muscle power (Jumping on one foot and Jumping on two feet), agility (5x10), and speed (20m run) were similar between boys and girls (p>0.05). Overweight or obesity predicted lower explosive muscle power, leg muscle power, speed until predictors were added, and hand muscle power (Medicine ball) after predictors were added. Covariates were able to

Table 2. Pairwise comparison of physical fitness indicators in one year

		The transition from 7 to 8 years		The transition from 8 to 9 years		The transition from 9 to 10 years	
Tests		**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
Standing broad jump	Time 1	115.71 (20.23)	103.37 (18.07)	116.03 (24.42)	114.02 (21.12)	128.64 (23.20)	118.17 (18.63)
	Time 2	129.21 (17.84)***	118.61 (16.74)***	132.95 (20.66)***	127.18 (21.41)***	148.43 (24.31)***	137.00 (22.41)***
Jumping on one foot	Time 1	3.62 (0.86)	3.93 (0.95)	3.53 (0.75)	3.69 (0.60)	3.28 (0.51)	3.48 (0.53)
	Time 2	3.43 (0.75)	3.48 (0.61)**	3.19 (0.59)**	3.18 (0.53)***	2.86 (0.55)***	2.96 (0.53)***
Jumping on two feet	Time 1	3.83 (0.95)	4.25 (0.85)	3.80 (0.78)	3.90 (0.67)	3.46 (0.76)	3.71 (0.55)
	Time 2	3.73 (0.85)	3.90 (0.62)	3.32 (0.72)***	3.28 (0.62)***	3.16 (0.72)***	3.15 (0.61)***
Tennis ball	Time 1	10.82 (2.98)	9.66 (4.52)	10.59 (3.95)	9.53 (3.00)	13.96 (5.28)	11.20 (3.67)
	Time 2	15.57 (4.04)***	12.28 (3.77)*	14.50 (4.61)***	14.41 (3.77)***	18.09 (2.86)***	15.66 (2.71)***
Medicine ball	Time 1	2.63 (0.65)	2.26 (0.62)	2.97 (0.86)	2.72 (0.65)	3.65 (0.80)	2.95 (0.63)
	Time 2	4.00 (0.70)***	3.47 (0.60)***	3.87 (0.89)***	3.86 (0.82)***	4.81 (0.92)***	3.99 (0.79)
Shuttle run 5×10	Time 1	23.31 (3.73)	24.60 (2.17)	23.89 (2.22)	23.64 (2.40)	22.85 (3.11)	22.57 (4.27)
	Time 2	22.17 (2.81)	22.82 (2.38)***	21.56 (2.99)***	21.58 (2.39)***	20.24 (2.40)***	21.14 (2.10)*
Shuttle run 20 m	Time 1	5.26 (0.50)	5.60 (0.45)	5.00 (0.80)	4.81 (0.83)	4.60 (0.76)	4.80 (0.46)
	Time 2	4.49 (0.71)***	4.56 (0.50)***	4.54 (0.53)**	4.56 (0.66)	4.12 (0.52)***	4.21 (0.64)***

Note: * - $p < 0.05$; ** - $p < 0.01$; *** - $p < 0.001$.

Table 3. Prediction of physical fitness among primary school children

Individual factors	Standing broad jump	Jumping on one foot	Jumping on two feet	Tennis ball	Medicine ball	Shuttle run 5x10	Shuttle run 20 m
Covariates							
Gender (female)	-0.11*/-0.10	0.03/-0.02	-0.01/0.01	-0.15**/0.18*	-0.18**/-0.18*	-0.02/0.10	0.03/0.06
Age	0.37**/0.22**	-0.33**/-0.32**	-0.41**/-0.33**	0.47**/0.34**	0.42**/0.18*	-0.22**/-0.24**	-0.53**/-0.22*
BMI (overweight, obese)	-0.11*/-0.14*	0.10*/0.07	0.09*/0.10	-0.06/-0.03	0.06/0.14*	-0.02/0.08	0.11*/0.08
Time 1 indicator for the corresponding test	0.39**/0.44**	0.35**/0.34**	0.27**/0.23**	0.28**/0.26**	0.15**/0.18*	0.18**/0.10	0.19**/0.15**
Predictors							
Inactivity (Time 1; >1 h/day)	0.01	0.02	0.01	0.10	0.02	0.24	-0.08
Light PA (Time 1; >1 h/day)	0.05	-0.05	-0.04	-0.003	-0.01	-0.23	0.02
MVPA (Time 1; >1 h/day)	0.02	-0.05	-0.02	0.01	0.08	-0.03	-0.16*
VPA (Time 1; >3.5 h/week)	0.06	-0.01	-0.06	0.18*	0.07	-0.12*	0.002
Sports (Time 1; not engaged)	-0.07	-0.04	0.03	0.06	-0.04	0.15*	0.11
Inactivity (Time 2; h/day)	0.01	0.07	0.01	0.07	0.11	0.80	-0.12
MVPA (Time 2; h/week)	0.09	-0.04	0.001	-0.07	0.09	-0.02	0.21
Motivation	0.07	-0.10	-0.11	0.06	-0.11*	-0.18*	-0.30**
ΔR^2(cov)/ΔR^2 (pred)	0.39***/0.03	0.30***/0.02	0.22***/0.02	0.28***/0.05	0.20***/0.05	0.13***/0.10***	0.16***/0.13**

Note: BMI – body mass index; PA – physical activity; MVPA – moderate to vigorous physical activity; VPA – vigorous physical activity; * - $p < 0.05$; ** - $p < 0.01$.

explain from 13 percent (agility) up to 39 percent (explosive muscle power).

Among predictors, vigorous physical activity at Time 1 predicted better performance in hand muscle power and agility at Time 2. Participation in sports at Time 1 also predicted better agility. Moderate to vigorous physical activity predicted better speed at Time 2. Motivation for physical activity at Time 2 is related to better agility and speed and worse hand muscle power. Predictors altogether were able to significantly explain 10 percent of agility and 13 percent of speed test results. Predictors explained 2 to 13 percent of physical fitness depending on the test.

Discussion

This study aimed to identify predictors of after-COVID-19 changes in the physical fitness of primary school children. Firstly, the results revealed that, as supposed in the previous research (Fransen et al., 2014), physical fitness in primary school children improves with age with some stagnation for some physical fitness characteristics at a certain age transition. For instance, the most stagnative transition for boys was the one from 7 to 8 years. In this period explosive muscle power, hand muscle power, and speed improved but leg muscle power and agility showed

no significant gain. There might be a premise that for those mostly first-graders their first year at school was not enough time to accumulate the effects of organized sports including school physical education and after-school sports, which children usually begin to practice as they start primary school. However, their natural physical activity deteriorated during the confinement in the previous year. 7-year-old children at baseline had lower VPA at baseline and less time spent in MVPA at follow-up than their older counterparts. Though these results are valid for both genders, still girls were less sedentary than boys at follow-up in this study, which probably contributed to their small improvements in physical fitness at this particular transition from 7 to 8 years. Despite all said above, a general trend observed that children improve their physical abilities one year after returning to school after COVID-19 confinement.

The increased over the year physical fitness discussed above was associated with different physical activity factors at baseline and follow-up. The importance of physical activity was obvious even after controlling for baseline physical fitness results, other sociodemographic characteristics, and body mass index. Namely, children who performed better at agility and muscle power tests had more vigorous physical activity at baseline based on their parents' evaluation. Engagement in sports at baseline was associated with better agility results at follow-up. The MVPA at baseline was related to a better performance in the speed test. Motivation to engage in physical activity at follow-up was related to better agility and speed performance. Physical activity indicators were more prominent in explaining speed and agility (13 and 10 percent, respectively) than other physical fitness qualities.

Other studies also found that children's muscular strength and endurance were associated with their total weekly PA minutes and participation in sports/dance (Chen et al., 2018). The UP&DOWN Study adds that the most active and less sedentary cluster of students has the best physical fitness among other clusters formed from health-related behavior patterns (Cabanas-Sánchez et al., 2018). Moreover, other researchers suggest that not minutes but intensity of physical activity that counts. Each modality of physical activity accumulates into better physical fitness in primary school children, however, results favored more intensive PA. In a similar study in Estonian children, researchers found that VPA at the age of 6 years was positively related to agility, explosive muscle power, and hand muscle strength at 12-month follow-up (Reisberg, Riso, Jürimäe, 2020). So, authors suggest that VPA is crucial for the development of motor fitness and agility in young children (Reisberg, Riso, Jürimäe, 2020), as well as is required in different types of sports and play (Miller et al., 2019). On the other hand, the relationships between sports, play, motivation towards physical activity, and physical fitness are reciprocal (Henning et al., 2022).

The current study did not indicate any impact of sedentary behavior on physical fitness either at baseline or at the follow-up. Meanwhile, other studies show the negative impact of sedentary behavior on upper and lower-body muscular strength (Reisberg, Riso, Jürimäe, 2020). After school, primary school children in our sample are sedentary for about 6.5 hours/day. However, most of them were engaged in afterschool sports (86 percent), and the mean time of engagement in MVPA was close to the recommended norm (6.24 hours/week versus 7 h/week). So, probably these sample characteristics compensated for the negative impact that sedentary behavior has on physical fitness.

There is no available scientific data on changes in primary school children's physical fitness after COVID-19 confinement. The current study is among the first in this area of research. A similar study in Spain, just in a sample of adolescents also found growth in physical fitness (upper body power, strength endurance, cardiovascular fitness, flexibility, and eye-hand coordination). That study also highlighted the importance of after-school sports to compensate for the negative effects of confinement on physical fitness (Carriedo et al., 2022). Physical fitness in French primary school children was measured right before and right after the confinement and showed a drastic decline in performance (Chambonnière et al., 2021). Another study in Greece, among adolescents found that after 5 months long confinement lower-body fitness, was impaired for both genders, but flexibility and upper-body fitness were impaired only in males (Tsoukos & Bogdanis, 2022). The EMOTIKON Project study also revealed that a cohort of third-graders after the confinement had lower physical fitness than is expected for their age (Teich et al., 2023).

The comparison of this data with pre-COVID-19 nationally representative results (Emeljanovas et al., 2020) showed inconsistent trends. Namely, at baseline explosive muscle power and upper body muscle power were lower in the post-COVID-19 sample than in the pre-COVID-19. However, leg muscle power and agility results were better in the after-COVID-19 sample. Pre- and post-COVID-19 studies in China with the same study participants also identified interesting facts. Namely, cardiorespiratory fitness and explosive force (i.e., 50-m sprint) deteriorated during the lockdown. However, muscular strength (i.e., pull-ups) improved. The deterioration was bigger for those adolescents who had greater physical fitness before the lockdown (Zhou et al., 2022).

Moreover, in the current study at follow-up, the results for particular age children were in most cases better than the results of their peers of the same age at baseline. That again confirms that returning to school and having regular physical education as well as after-school sports presumably accelerated the improvement in physical fitness. Systematic review and meta-analysis noticed that both quality and quantity-based physical education interventions contributed to an increase in physical and motor fitness (García-Hermoso et al., 2020). While some other studies add that to achieve significant improvement in physical fitness daily physical education is required (Greier et al., 2020; Erfle & Gamble, 2014). All previously mentioned characteristics of physical fitness are important for children's everyday functioning and play (Henning et al., 2022; Sandford et al., 2015), which promotes not only physical but also social and emotional well-being (Bento & Dias, 2017).

Still, covariates explained the higher percent of the variance than physical activity indicators. The baseline result of a particular physical fitness indicator was one of the most prominent predictors at follow-up for the same physical fitness indicator. The baseline result was the most prominent specifically for explosive muscle power. For agility, speed, and hand muscle power age was even more important for improvement. Baseline fitness results serve

as a crucial reference point for assessing progress over time. Differences in gender groups were found in explosive muscle power and leg muscle strength results, boys have performed better. Being overweight or obese predicted lower results of explosive muscle power, leg muscle strength, and speed after controlling for the rest covariates.

Absence of overweight is important for a child's health (Reilly & Kelly, 2011), life satisfaction (Lopez-Agudo & Marcenaro-Gutierrez, 2021), physical activity (Ortega et al., 2013), and academic performance (Kim & So, 2013). The current study identified 7 percent of overweight or obese primary school children. The prevalence of obesity in Lithuania is lower than in some other countries, however, its numbers have risen recently. Overweight and obesity in this study predicted lower explosive muscle power, leg muscle strength, and speed, but better hand muscle power, while controlling for other study variables. Similarly, another study found that body mass index was positively related to upper-body muscle power and negatively to explosive muscle power (Sacchetti et al., 2012). The study revealed better performance in explosive muscle power, leg muscle power, agility, flexibility, and cardiorespiratory tests for under/normal weight students compared to overweight/obese ones in the region of Emilia-Romagna region (Russo, 2020). Another research confirmed that body mass index among other body composition indicators affects physical fitness test results (Müller et al., 2022).

Limitations

We did not measure changes in predictors. Physical activity characteristics were measured with different instruments at each time point. Moreover, at Time 1 these characteristics were presented by children's parents and at Time 2 by primary school children themselves. Further, despite we did control for some factors looking into the unique impact of our predictors, there might be some other covariates that we have not controlled for like heredity, maturity level, and socioeconomic factors. Even though there was not the aim of the current study, it would be more valuable if we had measures right before the confinement as baseline results. That would allow us to better identify the impact of confinement with its restrictions on the physical fitness of primary school students.

Conclusions

The explosive muscle power, leg muscle power, hand muscle power, and upper body muscle power increase with age. Agility in boys is constantly increasing from 8 to 10 years and in girls from 7 to 10 years. The speed is constantly increasing as children become older.

As children grow and develop, their physical fitness levels tend to change in response to various factors including different physical activity indicators. Vigorous physical activity is uniquely related to a better performance in hand muscle power and agility a year later. Practicing moderate-to-vigorous physical activity uniquely contributes to greater motor fitness even after controlling for sociodemographic variables, baseline motor fitness values, current BMI, as well as other physical activity-related factors at the moment or a year before. Physical activity enjoyment is also associated with greater motor physical fitness in primary school children.

A year after COVID-19 confinement returning to normal life and having regular physical education, physical activities, and sports as well as perceiving enjoyment from physical activity contribute to improvements in physical fitness and consequently primary school children's health. Targeting these factors in any possible way in any life circumstances helps to maintain and/or strengthen children's health.

Conflict of Interest

The authors guarantee that no conflicts of interest exist.

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Зміна показників фізичної підготовленості дітей молодшого шкільного віку через рік після COVID-19 та її предиктори на індивідуальному рівні

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 3 табл., 58 джерел.

Мета дослідження. Метою дослідження було оцінити фізичну підготовленість та її динаміку протягом року серед дітей молодшого шкільного віку від 7 до 10 років з урахуванням індивідуальних факторів дитини (пов'язаних зі здоров'ям: фізична активність, малорухлива поведінка; та психосоціальних: задоволення від занять фізичною активністю).

Матеріали та методи. Дослідження включало вибірку з 902 учнів 1-3 класів (49% хлопців і 51% дівчат), які взяли участь у тестуванні показників фізичної підготовленості на початковому етапі дослідження та в подальших спостереженнях протягом року. Крім того, було зібрано дані шляхом проведення анкетування учнів та їхніх батьків. Стан фізичної підготовленості оцінювали за допомогою восьми з дев'яти тестових завдань із батареї тестів з 9 пунктів, розробленої Фйортофтом та ін. (2011 р.). Зріст та вагу досліджуваних осіб вимірювали за допомогою механічної стадіометричної платформи (Seca 274, Гамбург, Німеччина; TEM50.01%) та портативних електронних ваг — TANITA BC 420 SMA (Tanita Europe BV, Амстердам, Нідерланди), відповідно. Рівень фізичної активності, малорухливої поведінки, участі у заняттях спортом, задоволення від занять фізичною активністю було оцінено дітьми та батьками в різні періоди часу.

Результати. Результати вказують, що від початкового етапу дослідження до подальшого спостереження спостерігалося покращення показників фізичної підготовленості, з деякими винятками для окремих тестів та представників обох статей. Високий рівень фізичної активності на 1 етапі прогностично сприяв поліпшенню показників сили м'язів кисті (Std β — стандартизований бета-коефіцієнт = 0,18) та спритності (Std β = -0,12) на 2 етапі дослідження. Як показали результати, участь у заняттях спортом на 1 етапі також була прогностично пов'язана з покращенням показників спритності (Std β = 0,15). Заняття фізичною активністю від помірного до високого рівня інтенсивності на 1 етапі дослідження прогностично сприяло підвищенню показників швидкості під час 2 етапу (Std β = -0,16). Встановлено, що мотивація до занять фізичною активністю на 2 етапі була пов'язана з покращенням рівня спритності (Std β = -0,18) та швидкості (Std β = -0,30), при цьому спостерігалося зниження показників сили м'язів кисті (Std β = -0,11). Загалом, за допомогою предикторів вдалося суттєво роз'яснити 10% результатів тесту на спритність і 13% результатів тесту на швидкість.

Висновки. У процесі росту та розвитку дітей, рівень їхньої фізичної підготовленості має тенденцію змінюватися у відповідь на різні фактори, включаючи різні показники фізичної активності, а також мотивацію до виконання фізичних навантажень.

Ключові слова: фізична підготовленість, діти молодшого шкільного віку, лонгітюдне дослідження, рухова підготовленість, підготовленість опорно-рухової системи.

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REVIEW ARTICLE

Analyzing Handball Techniques Using A Biomechanical Approach: A Systematic Literature Review

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Abstract

Objectives. The study aimed to examine the use of biomechanical analysis in handball technique.

Materials and methods. This review study followed the PRISMA standards for systematic reviews and meta-analyses. The study had to be published within the period of 2018 to 2023. The search procedure involved using the keywords (1) handball and (2) biomechanics. Scopus search engine was used in the study.

Results. The search results on the database yielded 115 articles, which were adjusted according to the criteria into 11 articles.

Conclusion. Biomechanical analysis that can be applied to handball techniques includes such aspects: distance travelled, speed, change of direction, joint angle, postural stability, movement pattern, and injury localization.

Keywords: handball, biomechanics, technique.

Introduction

Handball players have significant asymmetry in body musculature and grip strength, which may impact performance and increase injury risk (Lijewski et al., 2021). Elite and sub-elite performers in beach handball are differentiated by horizontal jump and technical ability via the performance of specific throwing skills, rather than anthropometric or other physical variables (Lemos et al., 2022). The most frequent injuries in handball players are located in the lower limbs (thigh, knee, ankle), and in the shoulder in the upper limbs (Vila et al., 2022).

Systematic literature reviews provide a comprehensive understanding of a business literature topic, guide future research, and help business leaders make better decisions (Clark et al., 2021). Systematic reviews are invaluable for synthesising research findings and help demystify the search process (Foo et al., 2021). A search summary table in systematic reviews improves search results reporting and adds to the evidence base about information retrieval (Bethel et al., 2021).

Sports biomechanics examines athletic movements to enhance performance and reduce injury risk, with motion technologies being used in support of athletes (Aresta et al., 2023). Biomechanics in sports performance involves automating performance analysis and assessment by using motion capture sensors and biomechanical software to extract joint angle curves and summarize them into standard performance curves (Fathalla et al., 2023). Sports biomechanics aims to reduce injury risk and improve sports performance, with the Journal of Sports Sciences combining Sports Medicine and Biomechanics sections to form the current Sports Medicine and Biomechanics section (Wallace et al., 2022).

Different movement profiles of speed, acceleration, and tortuosity were identified across phases of play and in-game win probabilities (Gregory et al., 2022). Linear advancing actions are the most common movements preceding goals, followed by decelerations and turns (Martínez-Hernández et al., 2023). Attacking agility actions, such as side steps, shuffle

steps, crossover cutting, split steps, spins, decelerations, and sharp turns, are important maneuvers in invasion team sports to evade, create separation, generate high exit velocities, and facilitate sharp redirections (Dos'Santos et al., 2022).

There has been a long history of research on handball related to education (Arias et al., 2021), physicological (Muntianu et al., 2022), body composition (Martínez-Rodríguez et al., 2021). Some sports place great importance on biomechanics as an instrument of achievement. Biomechanics is considered a determining factor in athlete performance (Aresta et al., 2023; Wallace et al., 2022). Some of the previous studies that examined handball (Hidayat & Permana, 2023; Nurhadi et al., 2023) require updates regarding the importance of training techniques and biomechanics in this sport. This research can help in creating a training plan that suits the requirements of the sport. Therefore, this research is very important. The researchers hope that the findings from this study will provide recommendations for readers.

Materials and Methods

The research method used is a systematic literature review (SLR) for studying and interpreting biomechanical analysis on handball.

Study Participants

The population of this study were articles published in international journals indexed by a highly reputable database, namely Scopus, which is equivalent to the role of weight training in gymnastics athletes. The sample selected was articles with H-Index and articles published in international journals with Elsevier homepage from 2018-2023. This study has two types of research data sources, namely primary and secondary data sources. The instrument used in this research is a data coding sheet. This data not only serves as an internal audit, but is also useful in answering why certain studies are not included in the synthesis.

Data Collection Techniques and Instruments

a. Planning

The initial stage to start the systematic review process is planning by forming a review panel of experts and practitioners to develop a review question. Review questions will result in data analysis and synthesis. Review questions have been discussed in the problem formulation chapter.

b. Data Collection

The data collected in this study are secondary data obtained from the results of research that has been carried out by previous researchers and published in international journals indexed by a highly reputable database Scopus.

The article search used the keywords "biomechanical" AND "handball". In addition, the authors also checked the references of the articles searched to increase the number of article searches.

c. Inclusion and Exclusion Criteria

The inclusion criteria in this study:

1. The data used only relates to keywords.
2. Data is an original article.
3. Only English articles and indexed according to predetermined criteria.
4. Data used in the time span 2018-2023.

While the exclusion criteria are as follows:

1. Data that is not related to biomechanics in handball.
2. Data is not an original article including review articles.
3. Not an English-language article and indexed according to predetermined criteria.
4. Data used in the time range 2018-2023.

Searching for articles in the database using keywords obtained a total of 115 articles. After filtering by determining the publication period (2018-2023), language and type of article, 60 articles were obtained. Furthermore, the articles were selected based on inclusion and exclusion criteria according to relevance and a total of 11 articles were obtained (fig. 1).

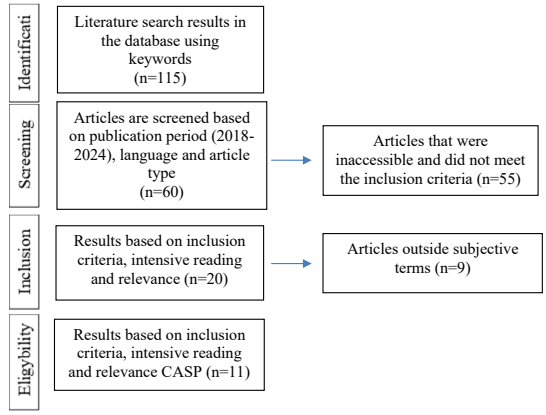

Fig. 1. PRISMA scheme in the literature selection process

Study Instrument

The researcher used annotated bibliography analysis. Several things were considered in analyzing the annotated bibliography, namely:

1. Identity of the referenced source.
2. Qualification and purpose of the author.
3. A simple summary of the content.
4. The importance of the sources referred to in answering the problem that has been formulated.

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 at year

Year of Publication	Number of article
2023	10
2022	9
2021	8
2020	8
2019	13
2018	12

Based on the articles that met the inclusion criteria, intensive reading and relevance to answer the research questions, 5 studies were eligible to proceed to the next stage. The collected studies were then analyzed using the mixed methods appraisal tool (MMAT) adapted from Hong (2018). The results of the MMAT analysis of the eleven quantitative studies in table 4 show that nine studies used random sampling using a control or comparison group.

Table 2. Source from country

Country	Number of article
Spain	10
Denmark	9
Germany	7
Norway	7
Poland	7
United Kingdom	6
United States	6
Austria	4
Brazil	4
France	4

Discussion

Based on results handball techniques is distance traveled, velocity, changes in direction, joint angle, postural stability, movement pattern, location injury. High levels of physical fitness and motor skill development, including the ability to jump, throw, sprint short distances, move quickly, have both anaerobic and aerobic capacity, and have strong muscles, are hallmarks of the handball sport (Dimkova, 2022). Running, direction changes with and without the ball, opponent interaction, and decision-making in both offensive and defensive activities are all part of the game (Fenici et al., 2022). Due to its comparatively quick mastery

Table 3. Mixed method apparaisal tool (MMAT) version 2018

	Screening Questions		Quantitative randomized controlled trial				
Author, year	Is question research questions clear?	Is collection data collection can answer questions research question?	2.1. Was randomization carried out appropriately?	2.2. Are the groups comparable from the beginning?	2.3. Is there is result data complete?	2.4. What is the intervention given confidentially (blind) to the results assessor?	2.5. Is participant obey intervention which given?
(Fathalla et al., 2023)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Müller et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Lijewski et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Wilczyński et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Russomanno et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Guignard et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(van den Tillaar et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Sánchez-Sáez et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Di Credico et al., 2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Vila et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(Wagner & Hinz, 2023)	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4. Review of research results

Title	Finding	Method
(Fathalla et al., 2023)	Observasional Study	Joint Angle
(Müller et al., 2022)	Observasional Study	Distance traveled, velocity, and changes in direction.
(Lijewski et al., 2021)	Observasional Study	Segmental bioelectrical impedance analysis (SBIA)/Angle
(Wilczyński et al., 2022)	Non RCT Trial	Postural stability and angle
(Russomanno et al., 2021)	Observasional Study	Movement
(Guignard et al., 2022)	Observasional Study	Movement
(van den Tillaar et al., 2021)	Non RCT Trial	Handball throws and predict ball velocity, offering a practical and automated method for quantifying throw counts and classifying approach and throw types.
(Sánchez-Sáez et al., 2021)	Observasional Study	Movement patterns and physical demands during an official competition.
(Di Credico et al., 2021)	Observasional Study	Bioelectrical characteristics in young male and female elite handball players.
(Vila et al., 2022)	Sistematic Literature Review	The most frequent injuries in handball players are located in the lower limbs (thigh, knee, ankle), and in the shoulder in the upper limbs.
(Wagner & Hinz, 2023)	Observasional Study	Specific game-based movements and general physical performance tests.

based on natural human movements, handball has become very popular very quickly (Śliż et al., 2022). In order to enhance technical processes during games and minimise injuries, the sport mandates that players follow particular physical training regimens depending on their position and level on the pitch (Russomanno et al., 2021). Handball is a dynamic and difficult sport that integrates motor skills, physical conditioning, and strategic decision-making.

Handball players experience frequent injuries in lower limbs (thigh, knee, ankle), upper limbs (shoulder), and playing positions (over the 6-m line, women), with most occurring during competition (Vila et al., 2022). Handball players cover more total distance in offense (1217.48 ± 699.33 m) and in all locomotion categories ($p < 0.001$) than in defense (900.96 ± 538.95 m), with a similar average total time on court (Manchado et al., 2021). Co-education in school handball leads to significant improvements in skills, effort, enjoyment, participation, and social climate, promoting social and civic skills (Arias et al., 2021).

The results of biomechanical evaluations are crucial for assessing athletic performance because they offer a more thorough understanding of a person's neuromuscular capabilities, which traditional testing may miss (Pleša et al., 2022). Understanding the mechanics of any sport is essential for improving performance and avoiding injuries, and biomechanics can help with this (Kumaran et al., 2022). Accurate performance data is provided by biomechanics-based performance analysis, which aids coaches and athletes in achieving optimal athletic performance (Teferi & Endalew, 2020). In order to determine the biological components that absorb shock and safeguard living systems, as well as to comprehend the stresses and strains that various body parts generate, biomechanics is used in the analysis of sports performance (Bandeiras, 2019). A thorough examination of the motions and coordination involved in sports like cycling can be obtained by biomechanical evaluation, which enables the accurate measurement of kinematic, kinetic, motor, and physiological traits (Turpin & Watier, 2020).

Absence of biomechanical analysis in training can result in a higher risk of injury and less than ideal performance (Bathe et al., 2023). Athlete movement patterns and mechanics can be better understood by biomechanical analysis, which also helps identify potential risk factors and opportunities for improvement (Chenaut et al., 2019; Yin et al., 2022). Coaches and athletes can lower the risk of injury and improve performance by implementing focused training interventions by being aware of and addressing these biomechanical risk factors (Jones et al., 2022). One prevalent risk factor for lower extremities landing injuries is knee flexion angle, which can be reduced to a medium extent by technique training and dynamic strengthening, as demonstrated by previous research (Naichun, 2018). Furthermore, in order to ensure the safety and effectiveness of exoskeletons for people with lower limb limitations, biomechanical analysis can aid in their design and optimisation. Thus, in order to reduce the chance of injury and optimise performance, athletes must integrate biomechanical analysis into their training regimens.

Conclusion

Based on the results of using techniques for analyzing handball biomechanics by searching related literature, it can be concluded that the biomechanical analysis that can be applied to handball techniques is distance traveled, velocity, changes in direction, joint angle, postural stability, movement pattern, location injury.

Conflict of Interest

The authors guarantee that no conflicts of interest exist.

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Аналіз технічних прийомів у гандболі з застосуванням біомеханічного методу: систематичний огляд літератури

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 4 табл., 1 рис., 39 джерел.

Мета дослідження. Дослідження мало на меті вивчити питання застосування біомеханічного аналізу в техніці гандболу.

Матеріали та методи. Дане оглядове дослідження проводилося відповідно до стандартів PRISMA для систематичних оглядів та мета-аналізів. Дослідження мали бути опубліковані в період з 2018 по 2023 рік. Процедура пошуку включала використання ключових слів (1) гандбол і (2) біомеханіка. У дослідженні було використано пошукову систему Scopus.

Результати. За результатами пошуку в базі даних було знайдено 115 статей, які були відібрані відповідно до критеріїв у кількості 11 статей.

Висновок. Біомеханічний аналіз, який можна застосувати до техніки гандболу, включає такі аспекти: пройдену відстань, швидкість, зміну напрямку, кут нахилу суглоба, постуральну стійкість, схему рухів і локалізацію травми.

Ключові слова: гандбол, біомеханіка, техніка.

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