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Spirographic study of functional reserves of masters' athletes in track-and field

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

Abstract

Background and Study Aim The progressive aging of the global population presents significant challenges, particularly in maintaining the functional reserves of vital systems. The respiratory system is crucial for sustaining physical performance. However, it is especially vulnerable to age-related decline. This study aims to assess the impact of structured physical activity on the respiratory function of sports-active veteran track-and-field athletes aged 50–59 and 60–75 years.

Material and Methods A total of 93 men were examined, including 54 in the reference group (30 men with an average age of 53.67±0.25 years and 24 with an average age of 67.08±0.35 years). These men were involved in athletics in the past but did not participate in veteran sports. The study group included 29 athletics veterans. Among them, 18 individuals had an average age of 52.27±0.18 years, and 11 had an average age of 65.64±0.16 years. These athletes engage in specifically organized physical activity 2–4 times a week and have participated in athletics competitions over the last five years. Anthropometric measurements included the assessment of chest circumference at rest, maximal inspiration, maximal exhalation, and diaphragmatic excursion (DE). The functional state of the respiratory system was assessed using the SpiroCom diagnostic complex (HAI). The data were processed using the SPSS Statistics 17.0 software.

Results Sports veterans aged 50–59 years and those over 60 years exhibit statistically significant differences compared to their peers in several indicators. These include diaphragmatic excursion, tidal volume, minute volume, respiratory rate, tidal volume maximal, respiratory rate maximal, and maximal voluntary ventilation. The respiratory reserve indicator showed a lower degree of respiratory function tension during physical exertion. Statistically significantly higher values of external respiration indicators were found in veteran athletes compared to men with no regular activity (NRA). These indicators include expiratory time, forced expiratory volume in 1 second, and forced expiratory volume maximal. Additionally, veteran athletes showed higher values in the modified Tiffeneau-Pinelli index, peak expiratory flow, and forced expiratory flow at 25%, 50%, 75%, and forced mid-expiratory flow. As a result, sports veterans with high regular activity (RA) exhibited the lowest rates of regressive-destructive changes in the respiratory system indicators overall, with the exception of HOD and BH. In contrast, men with low RA are characterized by an accelerated rate of aging in the respiratory system.

Conclusions The results of the study identified indicators that can serve as spirographic criteria for selecting functional types. These types include individuals with low, medium, and high regular activity (RA). It has been proven that systematic exercises involving specially organized cyclic motor activity form a rational, physiologically optimal type of breathing. Additionally, these exercises inhibit age-related degenerative-dystrophic processes in the human respiratory system.

Keywords: sports veterans, spirography, athletics, respiratory system

Introduction

The global aging of the population increasingly raises the issue of maintaining the functional

reserves of vital systems in the body. The respiratory system, in particular, is especially vulnerable to age-related changes and plays a crucial role in sustaining physical activity and overall health. This creates a need to find new solutions aimed at supporting and improving respiratory function in

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sports-active veterans involved in track and field. Such a need requires detailed study and analysis of their functional indicators.

According to the Population Reference Bureau, the aging of the population at the current stage is of great importance in the socio-economic life of countries worldwide [1]. The number of people over 65 years old in Europe accounts for 19% of the total population [2], while in Ukraine, this figure is 21.6% [3]. It has been established that the respiratory system undergoes significant morphological and functional changes during aging, affecting the chest, airways, lung parenchyma, and the pulmonary vascular system [4, 5]. Therefore, the study of age-related features of the respiratory system holds a prominent place within gerontological research. This is primarily due to the importance of the external breathing apparatus in supplying the body with oxygen. Hypoxic conditions are characteristic of older age and significantly impact the progression of age-related changes in various organs and systems. Additionally, there is a need to identify the causes and mechanisms that will help maintain respiratory system function in older age. Establishing age-related respiratory system criteria at later stages allows for distinguishing actual age-related changes from those caused by pathological processes [6].

Morphological changes in the respiratory apparatus during aging significantly affect the functional features of external breathing. As a result, with aging, the tidal volume decreases slightly, while the inspiratory reserve volume and expiratory reserve volume decrease more significantly. These changes in tidal volume, inspiratory reserve volume, and expiratory reserve volume lead to a decrease in lung vital capacity. The negative correlation of this indicator with age is reflected in vital capacity formulas [7, 8]. Additionally, with aging, the lung diffusion capacity decreases [9]. This decline is especially pronounced during physical exertion; the surface area of functioning alveolar epithelium, characterized by the number of alveoli and capillaries that are functionally connected, also decreases. By the age of 70, the total number of alveoli decreases by 40% compared to at 40 years old [10]. All these negative processes eventually lead to various diseases of the respiratory system and other body systems. According to research [11], mortality from respiratory system diseases ranks third worldwide.

One of the reasons for the sharp negative changes in the respiratory system is a decrease in the level of motor activity with aging [12]. As research by various authors shows, mental and physical abilities (such as maximum strength, endurance, and flexibility) can be effectively maintained at a high level, regardless of age, under regular training conditions [13, 14, 15, 16]. This is also evidenced

by the results of sports veterans who continue to train and compete in older age, and even in very old age. As noted by the authors [17, 18, 19, 20, 21], the decrease in physiological functions in these sports veterans is less significant compared to their peers who lead a sedentary lifestyle. It should be noted that scientific research on the influence of specially organized motor activity on the state of functional systems, particularly the respiratory system, in veteran athletes is rarely conducted.

The aim of the work: To investigate the impact of specially organized motor activity on the respiratory system of veteran athletes aged 50–59 and 60–75 years who participate in competitive activities.

Materials and Methods

Participants

A total of 93 men were examined, 54 of whom were in the reference group (30 men with an average age of 53.67 ± 0.25 years, and 24 with an average age of 67.08 ± 0.35 years). These men were involved in athletics in the past. The study group consisted of 29 experienced athletes: 18 men in the age group 50–59 years (average age 52.27 ± 0.18 years) and 11 men in the age group 60–75 years (average age 65.64 ± 0.16 years). These participants are consistently engaged in specially organized physical activity (2–4 times a week) aimed at achieving sports results and have participated in competitions at various levels over the past five years. All participants were healthy and reported no physical problems or illnesses.

Research Design

To assess motor activity, participants were asked to keep a physical activity diary over a two-month cycle. Among the sports veterans, subgroups were identified based on their average number of training days per year. There were 12 people (66.67%) in the age category of 50–59 years and 6 people (54.55%) in the age category of 60–75 years with an average of 80–140 training days per year. Additionally, a high level of physical activity (more than 140 training days per year) was observed in 6 people (33.33%) in the 50–59 years category and 5 people (45.45%) in the 60–75 years category. Anthropometric studies included the measurement of thorax circumference at rest (ThCp), on maximal inspiration (ThCi), on maximal expiration (ThCe), and diaphragmatic excursion (DE).

The analysis of the functional state of the external breathing apparatus was carried out using the SpiroCom diagnostic complex (HAI, Ukraine). As part of the mandatory set of functional tests in spirometry, a test of calm breathing and three special breathing maneuvers were performed to determine vital capacity (VC), forced vital capacity (FVC), and maximal voluntary ventilation (MVV). The registration and processing of spiograms were divided into six stages: changes in tidal volume (TV),

changes in inspiration and expiration vital capacity, recording of forced inspiration and expiration, and determination of maximal voluntary ventilation. When recording rest breathing and tidal volume, the subjects breathed with their natural frequency and depth of breathing (for 40–50 seconds). Based on the sample data, the following average values were calculated:

- TV – tidal volume (l);
- VE – minute volume (l);
- RR – respiratory rate (min^{-1});
- Ti – inspiratory time (sec);
- Te – expiratory time (sec);
- Ti/Te – inspiratory/expiratory ratio;
- RRmax – respiratory rate maximal (min^{-1});
- TVmax – tidal volume maximal (l);
- VC – vital capacity (l);
- IRV – inspiratory reserve volume (l);
- ERV – expiratory reserve volume (l);
- FVC – inspiratory (expiratory) forced vital capacity (l);
- FEV1 – forced expiratory volume in 1 second (l);
- FEVPEF – forced expiratory volume maximal (l);
- FEV1/FVC – modified Tiffeneau-Pinelli index (%);
- PEF – peak expiratory flow ($l \cdot \text{sec}^{-1}$);
- FEF25 – forced expiratory flow at 25% FVC ($l \cdot \text{sec}^{-1}$);
- FEF50 – forced expiratory flow at 50% FVC ($l \cdot \text{sec}^{-1}$);
- FEF75 – forced expiratory flow at 75% FVC ($l \cdot \text{sec}^{-1}$);
- FEF25-75 – forced mid-expiratory flow ($l \cdot \text{sec}^{-1}$);
- FEF75-85 – forced expiratory flow 75–85% ($l \cdot \text{sec}^{-1}$);
- TPEF – time of peak expiratory flow (sec);
- MVV – maximal voluntary ventilation ($l \cdot \text{min}^{-1}$).

Statistical analysis

Statistical processing of the results was carried out using SPSS Statistics 17.0. The data were tested for normality distribution using the Shapiro-Wilk test. Since the studied samples were small ($7 \leq n \leq 30$), the Mann-Whitney test was used to determine the significance of differences in the indicators. The significance of differences was accepted at a level of $p \leq 0.05$. All research results are expressed in the standard form as $\bar{x} \pm SE$.

Results

We studied the spirographic indicators of respiratory volume changes in veteran athletes aged 50–59 and 60–75 years who are consistently engaged in training aimed at achieving sports results and compared them with the corresponding indicators of people of the same age with a low habitual motor activity level (Table 1). As the data analysis showed, sports veterans aged 50–59 with moderate regular activity (MRA) and high regular activity (HRA)

have statistically significant differences compared to their peers in indicators such as DE (UCPA=27; UBPA=1; $p < 0.01$), TV (UCPA=144.5; UBPA=27.5; $p < 0.01$), VE (UCPA=53.5; UBPA=36.5; $p < 0.01$), RR (UCPA=179.5; $p < 0.05$; UBPA=56.5; $p < 0.01$), TVmax (UCPA=43.5, $p < 0.01$; UCPA=102, $p < 0.05$), RRmax (UCPA=143.5; UCPA=102, $p < 0.05$), and MVV (UCPA=46; UBPA=57; $p < 0.01$).

When analyzing the obtained values for this age category, we can state that indicators such as DE ($U=179.5$; $p < 0.05$) and RRmax ($U=62$; $p < 0.05$) are statistically significantly better in veteran athletes with high RA compared to those with moderate RA.

Under the influence of systematic sports training, veteran athletes who train regularly at least three times a week show clear benefits. Compared to their peers who train less than three times a week, they exhibit a significant decrease in breathing frequency at rest. Additionally, these athletes demonstrate relatively greater pulmonary ventilation values both at rest and under standard loads.

A similar pattern is observed in veteran athletes aged 60–75. Statistically significant differences compared to peers with low RA were found in indicators such as DE (UCPA=24; UBPA=23; $p < 0.01$), TV (UCPA=9.5; $p < 0.01$; UBPA=11; $p < 0.01$), and RR (UCPA=191.5; $p < 0.05$; UBPA=60; $p < 0.01$). The differences also extend to RRmax (UCPA=191.5; $p < 0.05$; UBPA=60; $p > 0.01$), TVmax (UCPA=5.5; UBPA=0.5; $p < 0.01$), and MVV (UCPA=79; UBPA=38.5; $p < 0.01$).

Also, in this age category, indicators such as DE ($U=0$; $p < 0.01$), RRmax ($U=46$; $p < 0.01$), and MVV ($U=44$; $p < 0.01$) were significantly better in veteran athletes with high RA compared to those with moderate RA.

It should be noted that the majority of the studied participants had a normal inhalation to exhalation ratio, which ranged from 1.11 to 1.53.

Based on the obtained indicators, we calculated the breathing reserve (BR) during the pulmonary stress test. This value provides information about the degree of respiratory function tension and the load on the respiratory system. For example, in men aged 50–75 years with low RA, respiratory reserves ranged from 7.22% to 13.64%. In sports veterans with moderate RA, BR was within the lower limit of the norm (23.22%–23.35%). In contrast, sports veterans with high RA had BR within the upper limit range (38.18%–41.12%).

The characteristics of external breathing functional tests in men aged 50–59 and 60–75 years with different levels of RA are presented in Table 2. Compared with men with low RA, the average value of VC in sports veterans with moderate RA and high RA aged 60–75 years is statistically significantly higher by 35.78% (UCPA=67.5; $p < 0.01$) and 56.55% (UBPA=22; $p < 0.01$), respectively. Among sports veterans aged 50–59, VC is higher by 37.43%

Table 1. Characteristics of functional tests of respiratory volume changes of sports veterans and men aged 50–75 who are not engaged in sports, $\bar{x} \pm SE$.

Indicators	Age group	Contingent categories		
		Men with low PA	Ssports veterans with moderate PA	Sports veterans with high PA
DE, cm	50–59	4.40 ± 0.23	7.74 ± 0.11*	8.25 ± 0.12*†
	60–75	3.11 ± 0.19	7.23 ± 0.14*	7.86 ± 0.12*†
TV, l	50–59	0.53 ± 0.04	0.71 ± 0.06*	0.77 ± 0.09*
	60–75	0.49 ± 0.02	0.58 ± 0.02*	0.66 ± 0.05*
VE, l · min ⁻¹	50–59	6.99 ± 0.52	9.05 ± 0.49*	7.75 ± 0.65
	60–75	6.54 ± 0.46	9.70 ± 0.61*	9.15 ± 0.65*
RR, min ⁻¹	50–59	22.21 ± 0.74	14.85 ± 0.88*	11.58 ± 0.32*†
	60–75	24.82 ± 0.76	16.74 ± 0.91*	15.18 ± 0.76*
T _i , sec	50–59	1.44 ± 0.07	1.41 ± 0.09	1.27 ± 0.08
	60–75	1.23 ± 0.05	1.17 ± 0.07	1.11 ± 0.06
Te, sec	50–59	1.61 ± 0.05	1.63 ± 0.07	1.65 ± 0.13
	60–75	1.68 ± 0.18	1.69 ± 0.08	1.75 ± 0.15
T _i /T _e	50–59	0.91 ± 0.03	0.87 ± 0.04	0.78 ± 0.03*
	60–75	0.77 ± 0.03	0.76 ± 0.04	0.75 ± 0.04
RR _{max} , min ⁻¹	50–59	76.50 ± 3.73	66.31 ± 3.36*	61.12 ± 1.67*
	60–75	79.43 ± 3.15	65.80 ± 3.32	67.05 ± 2.15
TV _{max} , l	50–59	1.50 ± 0.05	1.87 ± 0.06*	1.93 ± 0.09*
	60–75	1.07 ± 0.04	1.81 ± 0.05*	1.99 ± 0.08*
MVV, l · min ⁻¹	50–59	106.30 ± 2.70	161.50 ± 3.31*	167.50 ± 3.32*
	60–75	96.60 ± 2.30	155.40 ± 2.49*	165.20 ± 3.78*†

Note. * – statistically significant difference in parameters in relation to men with low RA; † – statistically significant difference in parameters between sports veterans with moderate RA and high RA; DE: diaphragmatic excursion; TV: tidal volume; VE: minute volume; RR: respiratory rate; T_i: inspiratory time; T_e: expiratory time; T_i/T_e: inspiratory/expiratory time ratio; RR_{max}: maximal respiratory rate; TV_{max}: maximal tidal volume; MVV: maximal voluntary ventilation.

(UCPA=64.5; $p < 0.01$) and 52.86% (UBPA=94.5; $p < 0.01$) (Fig. 1a, 1b).

A similar pattern was observed for the FVC indicator, where the average values were higher by 56.51% (UCPA=48; $p < 0.01$) and 69.18% (UBPA=55; $p < 0.01$) in sports veterans with moderate RA and high RA aged 50–59, and by more than 43.37% (UCPA=45; $p < 0.01$) and 63.08% (UBPA=55.5; $p < 0.01$), respectively, among sports veterans aged 60–79. As we can observe, with the increase in physical training, FVC increases above 90% of VC: 95.01% and 93.08% in sports veterans aged 50–59 years with moderate RA and high RA, respectively; and 94.12% and 92.86%, respectively, in sports veterans over 60 years old. In untrained men, FVC was 77.71% at the age of 50–59 and 76.36% at the age of over 60.

In addition, the difference in VC between men in this age range with low RA and high RA is outside the normal range (200–300 ml), indicating a negative effect from both the absence of physical activity and very intense sports on the airway

resistance of small bronchi. This difference is within the normal limits for men with moderate RA. The negative impact of training four times a week is also evidenced by a longer period of exhalation at rest compared to the reference group and sports veterans with moderate RA.

It should be noted that in veteran athletes aged 50–59 years who are regularly engaged in sports, there are statistically significant higher values of external breathing parameters compared to men with low RA. Specifically, the ERV is higher by 78.57% (UCPA=15; $p < 0.01$) and 97.96% (UBPA=30; $p < 0.01$). The FEV₁ is higher by 80.85% (UCPA=1; $p < 0.01$) and 85.11% (UBPA=0; $p < 0.01$). The FEV_{PEF} is higher by 25.76% (UCPA=113.5; $p < 0.01$) and 43.94% (UBPA=49; $p < 0.01$). The FEV₁/FVC is higher by 36.81% (UCPA=3; $p < 0.01$) and 30.78% (UBPA=4.5; $p < 0.01$). The PEF is higher by 53.27% (UCPA=0; $p < 0.01$) and 70.33% (UBPA=0; $p < 0.01$). The FEF₂₅ is higher by 32.47% (UCPA=3; $p < 0.01$) and 52.84% (UBPA=0; $p < 0.01$). The FEF₅₀ is higher

Table 2. Characteristics of functional tests of external breathing of sports veterans and men aged 50–75 who do not do sports, $\bar{x} \pm SE$.

Indicators	Age group	Contingent categories		
		Men with low PA	Sports veterans with moderate PA	Sports veterans with high PA
VC, l	50–59	3.50 ± 0.11	4.81 ± 0.10*	5.35 ± 0.07*†
	60–75	3.13 ± 0.05	4.25 ± 0.07*	4.90 ± 0.09*†
IRV, l	50–59	2.00 ± 0.05	2.32 ± 0.08*	2.54 ± 0.06*†
	60–75	1.76 ± 0.05	2.25 ± 0.07*	2.40 ± 0.03*
ERV, l	50–59	0.98 ± 0.04	1.75 ± 0.06*	1.94 ± 0.11*
	60–75	0.88 ± 0.03	1.45 ± 0.05*	1.90 ± 0.09*†
FVC, l	50–59	2.92 ± 0.05	4.57 ± 0.07*	4.94 ± 0.10*
	60–75	2.79 ± 0.05	4.00 ± 0.07*	4.45 ± 0.09*
FEV1, l	50–59	2.35 ± 0.05	4.25 ± 0.09*	4.35 ± 0.08*
	60–75	2.22 ± 0.05	3.75 ± 0.10*	3.9 ± 0.07*
FEV _{PEF} , l	50–59	0.66 ± 0.03	0.83 ± 0.04*	0.95 ± 0.08*
	60–75	0.56 ± 0.02	0.68 ± 0.03*	0.94 ± 0.08*†
FEV ₁ /FVC, %	50–59	69.18 ± 0.81	96.00 ± 1.18*	91.77 ± 1.52*†
	60–75	71.66 ± 0.80	85.42 ± 1.06*	87.64 ± 1.54*
PEF, l · sec ⁻¹	50–59	4.28 ± 0.10	6.56 ± 0.11*	7.29 ± 0.10*†
	60–75	4.20 ± 0.10	5.73 ± 0.15*	6.79 ± 0.15*†
FEF ₂₅ , l · sec ⁻¹	50–59	3.88 ± 0.06	5.14 ± 0.10*	5.93 ± 0.06*†
	60–75	3.76 ± 0.06	4.69 ± 0.11*	5.51 ± 0.08*†
FEF ₅₀ , l · sec ⁻¹	50–59	3.67 ± 0.10	4.12 ± 0.14	4.87 ± 0.16*†
	60–75	3.27 ± 0.10	3.92 ± 0.15*	4.67 ± 0.13*†
FEF ₇₅ , l · sec ⁻¹	50–59	2.88 ± 0.06	3.19 ± 0.10*	3.98 ± 0.05*†
	60–75	2.25 ± 0.07	3.09 ± 0.18*	3.79 ± 0.19*†
FEF ₂₅₋₇₅ , l · sec ⁻¹	50–59	3.95 ± 0.22	4.36 ± 0.37	5.25 ± 0.27*
	60–75	2.68 ± 0.18	3.17 ± 0.34	4.56 ± 0.24*†
FEF ₇₅₋₈₅ , l · sec ⁻¹	50–59	2.32 ± 0.12	2.41 ± 0.19	2.72 ± 0.31
	60–75	1.86 ± 0.19	2.31 ± 0.18	2.70 ± 0.24*
T _{PEF} , sec	50–59	0.15 ± 0.01	0.13 ± 0.01	0.12 ± 0.02
	60–75	0.24 ± 0.02	0.21 ± 0.02	0.13 ± 0.01*†

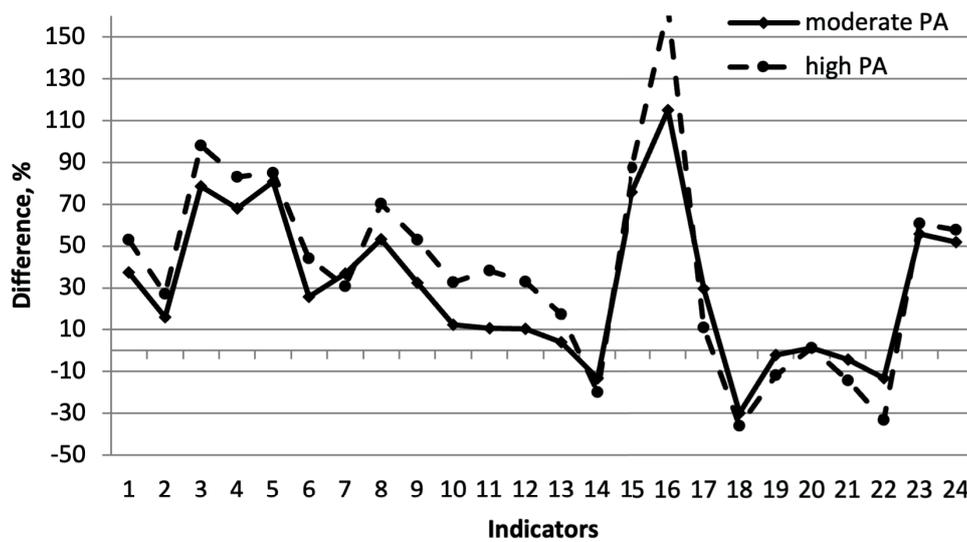
Note: * – statistically significant difference in parameters compared to the reference group; † – statistically significant difference in parameters between sports veterans with moderate RA and high RA; VC: vital capacity; IRV: inspiratory reserve volume; ERV: expiratory reserve volume; FVC: forced vital capacity; FEV1: forced expiratory volume in one second; FEVPEF: forced expiratory volume maximal; FEV1/FVC: Tiffeneau-Pinelli index; PEF: peak expiratory flow; FEF25, FEF50, FEF75: forced expiratory flow at 25%, 50%, 75% FVC; FEF25-75: forced mid-expiratory flow; FEF75-85: forced expiratory flow at 75–85% FVC; TPEF: time of peak expiratory flow.

by 32.70% (UBPA=10.5; $p < 0.01$). The FEF75 is higher by 10.76% (UCPA=137.5; $p < 0.01$) and 68.44% (UBPA=0; $p < 0.01$). Finally, the FEF25-75 is higher by 32.91% (UBPA=87.5; $p < 0.01$).

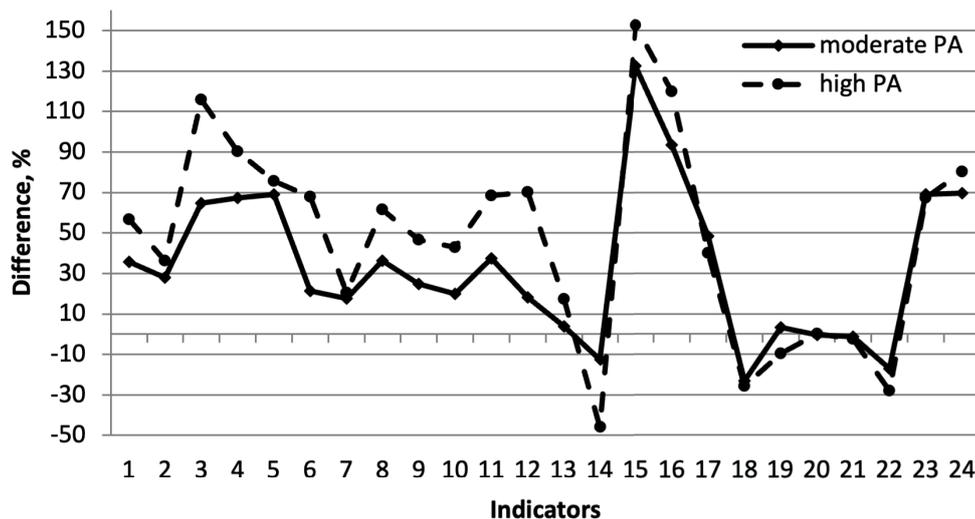
In sports veterans over 60 years old, similar differences were observed, along with additional differences in the TPEF (UBPA=45.5; $p < 0.01$) for sports veterans with high RA (Fig. 1b). We also determined the rates of destructive (regressive)

changes in the respiratory system indicators of men with a 10-year age difference (Fig. 2).

As can be seen from Figure 2, the lowest rates of regressive-destructive changes in the respiratory system indicators, in general, except for VE and RR, are typical for sports veterans with high RA. Men with low RA are characterized by an accelerated rate of respiratory system aging.



a)



b)

Figure 1. Spirographic profile of sports veterans aged a) 50–59 years and b) 60–75 years with different motor activity levels (in % relative to persons with low RA): 1 – vital capacity; 2 – inspiratory reserve volume; 3 – expiratory reserve volume; 4 – forced vital capacity; 5 – forced expiratory volume in one second; 6 – forced expiratory volume maximal; 7 – Tiffeneau-Pinelli index; 8 – peak expiratory flow; 9 – forced expiratory flow at 25% FVC; 10 – forced expiratory flow at 50% FVC; 11 – forced expiratory flow at 75% FVC; 12 – forced mid-expiratory flow; 13 – forced expiratory flow 75–85%; 14 – time of peak expiratory flow; 15 – diaphragmatic excursion; 16 – tidal volume; 17 – minute volume; 18 – respiratory rate; 19 – inspiratory time; 20 – expiratory time; 21 – inspiratory/expiratory ratio; 22 – maximal respiratory rate; 23 – maximal tidal volume; 24 – maximal voluntary ventilation.

Discussion

The aim of this study was to investigate the impact of regular, organized physical activity on the respiratory system of veteran athletes aged 50–59 and 60–75 years. The results demonstrated that sports veterans with high levels of physical activity exhibited significantly lower rates of regressive-

destructive changes in respiratory system indicators compared to their peers with low physical activity. This was particularly evident in parameters such as vital capacity (VC) and forced vital capacity (FVC), where veterans with higher activity levels showed markedly better performance.

Over the last 50 years, physiologists have

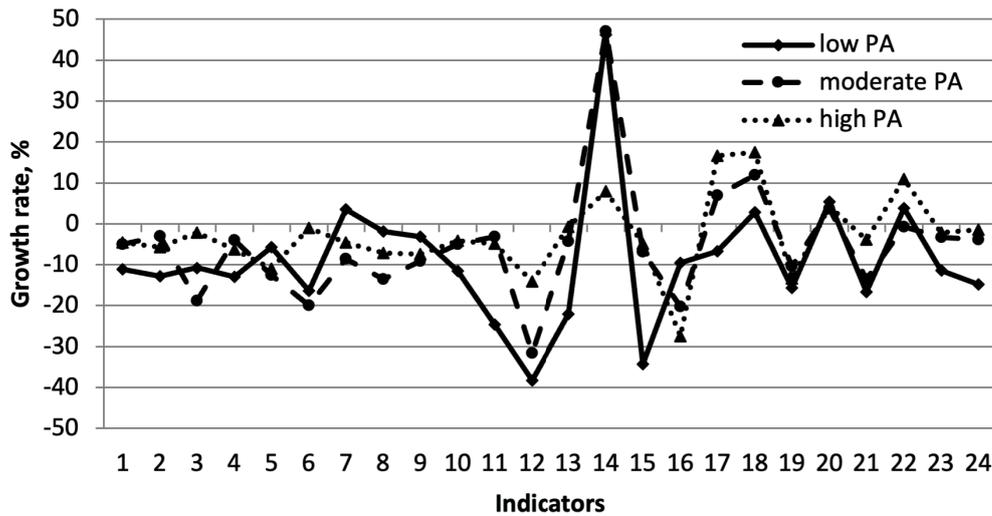


Figure 2. Rates of regressive changes in the respiratory system indicators of sports veterans and men with low RA: 1 – vital capacity; 2 – inspiratory reserve volume; 3 – expiratory reserve volume; 4 – forced vital capacity; 5 – forced expiratory volume in one second; 6 – forced expiratory volume maximal; 7 – Tiffeneau-Pinelli index; 8 – peak expiratory flow; 9 – forced expiratory flow at 25% FVC; 10 – forced expiratory flow at 50% FVC; 11 – forced expiratory flow at 75% FVC; 12 – forced mid-expiratory flow; 13 – forced expiratory flow at 75–85% FVC; 14 – time of peak expiratory flow; 15 – diaphragmatic excursion; 16 – tidal volume; 17 – minute volume; 18 – respiratory rate; 19 – inspiratory time; 20 – expiratory time; 21 – inspiratory/expiratory ratio; 22 – maximal respiratory rate; 23 – maximal tidal volume; 24 – maximal voluntary ventilation.

conducted a significant number of studies on the functional state of the external respiratory system, both at rest and under conditions of increasing standard physical exertion, in an ontogenetic context [22, 23, 24, 25, 26]. We established a decrease in the functional capabilities of the respiratory system with aging in both men who are not engaged in specially organized physical activity and in veteran athletes, as emphasized in work [27]. However, this decrease in the functional reserves of the respiratory system occurs at a significantly higher rate in non-athletes.

Under the influence of systematic sports training, compared to non-athletes of the same age, sports veterans experience a distinct decrease in breathing frequency, and relatively smaller values of pulmonary ventilation are observed both at rest and during standard loads, as confirmed in works [28, 29].

Many authors have noted that the intensification of external breathing during physical exertion occurs to a greater extent due to an increase in breathing depth and to a lesser extent due to an increase in respiratory rate [30]. This finding was confirmed by our study, where TVmax in sports veterans aged 50–59 and over 60 years was 26.67% and 77.57% higher, respectively, while the average values of RRmax were lower by 6.03% and 2.10%, respectively. Therefore, during exercise, lung ventilation can be enhanced both by an increase in tidal volume and by respiratory rate, with a

significant reduction in respiratory cycle duration, leading to an overall increase in the productivity of the respiratory process.

Among sports veterans, quite high values of lung excursion were noted, with the difference being approximately 82% in those aged 50–59 years, and 1.5 times greater in those over 60 years old, which coincides with the results of previous studies [31, 32]. This is due to the fact that intensive training can lead to improvements in respiratory muscle strength, reaching the maximum upper limit of the respiratory muscle functional reserve and corresponding diaphragmatic excursion. Additionally, targeted training of respiratory muscle strength can be an effective strategy to increase ventilatory function in less physically prepared individuals [33].

As for the ratio of inhalation to exhalation duration, which characterizes the balance between ventilation and oxygenation, it is known that under normal conditions with calm breathing, it is equal to 1:1.2 (maximum 1:1.5). During obstructive processes, this ratio changes to 1:2 and sometimes even 1:3. The obtained values of this ratio indicate an increase in average pressure in the respiratory tract, which contributes to better oxygenation due to CO₂ removal. However, the disadvantage is greater hemodynamic instability and the possibility of gas retention, especially in volume-depleted men, such as those with low RA [34, 35].

The studies [36, 37] emphasize a significant increase in vital capacity (more than 70%) in sports veterans compared to untrained men, which is confirmed by our results. An important fact is that the higher the VC, the lower the external breathing apparatus consumption.

A crucial functional indicator of external breathing is the forced vital capacity (FVC) of the lungs. In healthy men, FVC typically ranges between 70–80% of the actual VC. With increased physical training, FVC rises above 80% [38], as confirmed by our results.

As our studies have shown, the difference between VC and FVC in sports veterans with high RA and non-athletes exceeds the normal range (200–300 ml), while it remains within this range in veteran athletes with moderate RA. This suggests that endurance physical training can cause narrowing of the small bronchi, leading to reduced bronchial patency during forced exhalation. The negative impact of training four times a week for sports veterans over 60 years old is also indicated by a longer exhalation period at rest compared to athletes with low and moderate RA, as mentioned in works [39, 40].

It is known that during exercise, the TVmax of athletes can increase up to 4 liters. However, an increase in respiratory volume above 40–60% of VC leads to uneconomical respiratory system function. In our study, this ratio was in the range of 34.19–42.86%, indicating a physiologically rational type of breathing.

One of the main and valuable functional indicators of external breathing is the maximum lung ventilation in 1 minute (MVV). Normally, MVV reaches 80–100 l · min⁻¹. In athletes who primarily train for endurance, MVV can reach 130–150 l · min⁻¹ or more [41, 42], which we observed in sports veterans aged 50–59 years and over 60 years.

It is believed that an MVV level of 120 l is a critical limit, beyond which the energy consumption of the external breathing apparatus becomes particularly high. Achieving the limit values of pulmonary ventilation, characteristic of highly skilled athletes, results from the high coordination of respiratory acts with the contraction of respiratory muscles [43, 44].

According to data [45, 46], most of the absolute and relative indicators of external respiration (VC, MVV, etc.) in athletes of various ages (especially men) who primarily train for endurance are significantly higher than in those who train in other sports. This, in some way, reflects the degree of long-term extensive load influence on the external respiratory system.

As our studies have shown, the average value of breathing reserve in men aged 50–75 years with low RA indicates a decrease in their ability to perform physical exercises, while in sports veterans it remains within the physiological norm [47].

On the other hand, as our data showed, intensive training four or more times a week, while having positive effects, also has a negative impact on the respiratory system [48, 49], as observed in our research.

Veteran athletes, compared to men with low RA aged over 60 years, exhibit a more pronounced difference in the average values of external breathing indicators, which is evidenced by lower rates of regressive changes in sports veterans. Additionally, for men in this age group, even a slight increase in motor activity leads to a significant improvement in overall respiratory system functioning.

The results of our study confirmed the significant impact of regular physical activity on the functional indicators of the respiratory system in veteran athletes. However, it is important to note that intensive training can have both positive and negative effects on the respiratory system, particularly in men over 60 years old. The limitations of this study include a relatively small sample size and the lack of data on the long-term effects of training. Future research could focus on exploring the mechanisms of respiratory system adaptation to different levels of physical activity and identifying optimal training regimens for maintaining and improving respiratory health in older adults.

Conclusions

The analysis of the results from the conducted research made it possible to identify indicators that can serve as spirometric criteria for selecting functional types, specifically those with low, medium, and high PA. It has been proven that systematic exercises involving specially organized cyclical motor activity help form a rational, physiologically optimal type of breathing and inhibit age-related degenerative-dystrophic processes in the human respiratory system. Further work is required to determine the peculiarities of the functional reserves of the respiratory system in masters athletes, depending on the specific track and field events.

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Dribbling emotions and anxiety in women's football: a scoping review

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

Abstract

Background and Study Aim Fear of failure, choking under pressure, financial disparities in income, and concerns related to body image and social pressure may intensify on-field challenges. These factors make the competitive environment particularly demanding for female soccer players. The aim of the current review is to map the available evidence on anxiety in women's football over the past decade and to identify interventions designed to manage anxiety among female soccer players.

Material and Methods A scoping review was conducted following the PRISMA-ScR guidelines. An extensive search was carried out across four major databases for publications dated between 2014 and 2024. Two independent reviewers screened titles and abstracts, followed by full-text screening and data extraction. Any disagreements were resolved by a third researcher. The findings were tabulated and synthesized in a narrative format. The study was pre-registered on the Open Science Framework.

Results The search yielded 2885 unique records. A total of 21 texts were reviewed in full, and the final sample included 14 studies. Some of the records included mentioned modifications to psychosocial interventions, such as Virtual Reality (VR) relaxation sessions, pre-exercise sporting massage, and psychological training programs (including psycho-neuromuscular theory and visualization techniques). These interventions led to a reduction in anxiety, though their effectiveness varied significantly across different approaches. Our results suggest that research on women's football may disproportionately focus on psychological interventions for managing anxiety. This highlights the need for broader investigations into other factors that influence athletes' performance and well-being.

Conclusions This scoping review helps clarify the current landscape of anxiety research in women's soccer. It highlights both promising interventions and gaps in the research over the past decade. Although the body of evidence on anxiety interventions is small, it suggests that psychological interventions may be effective in reducing anxiety among female soccer players.

Keywords: anxiety, women soccer, female football, psychology, scoping review

Introduction

Anxiety is a significant factor that can impact performance and well-being in competitive sports. In women's football, this issue is particularly concerning due to the unique pressures' female athletes face. These pressures include societal expectations, gender-based comparisons, and the struggle for equal recognition and support in the sport. Despite the critical role that anxiety plays in influencing performance, the research on this topic within women's football is not as robust as it is in men's soccer.

This disparity raises important questions about how well current research addresses the specific needs of female athletes. In this context, despite growing interest in this area, studies on

anxiety among female soccer players have not yet achieved the same depth and breadth as research on their male counterparts [1]. This legacy of male-centric sports coverage has shaped the research environment. Men's football, with its longer history of institutional support, continues to attract more attention. This is particularly evident in fields like sports medicine research, strength and conditioning, and sociology. In comparison, women's football receives significantly less focus [2, 3, 4].

Stereotypes, disproportionately directed funding toward men's sports, and limited media coverage of women's sports reflect broader patterns of gender inequality in sports financing. These factors perpetuate the perception that sports remain predominantly focused on men and contribute to the existing imbalance [5, 6, 7].

In the evolving landscape of sports psychology, a notable gap remains in the empirical exploration of anxiety among women football players, despite the

pressing need for enhanced attention, awareness, and targeted interventions [8, 9]. This lack of targeted research leaves a void in understanding how anxiety impacts performance, well-being, and the overall athletic experience for female players.

The purpose of this study is to map the evidence on anxiety in women’s football over the past decade and to identify interventions designed to improve anxiety management among female soccer players.

Methodology

The pre-registration of this study was uploaded to the Open Science Framework (OSF) on July 6, 2024 (<https://osf.io/bd95z/>). The PRISMA extension for scoping reviews (PRISMA-ScR) was employed. This approach is increasingly used to generate evidence on a topic and identify research gaps [10].

Search strategy

On June 27, 2024, a comprehensive search for potentially relevant documents on anxiety was conducted using the software “Publish or Perish” [11] across four electronic bibliographic databases: PubMed, Scopus, CrossRef, and Google Scholar. A broad set of keywords was used to identify the specified literature:

- (1) “women” AND “soccer” AND “anxiety”;
- (2) “female” AND “football” AND “anxiety”;
- (3) “fear” AND “female” AND “football”;
- (4) “female” AND “soccer” AND “cognitive”;
- (5) “female” AND “soccer” AND “somatic”;
- (6) “female” AND “soccer” AND “trait”;
- (7) “female” AND “soccer” AND “trait anxiety”;
- (8) “female” AND “soccer” AND “state anxiety.”

Article search and selection procedures were performed independently by two researchers (EAT and VP). The full article screening was restricted to freely available full-text papers. Any disagreements were resolved by a third reviewer (GT).

Study eligibility

To be included in the review, papers needed to focus on anxiety among women football players, be published between 2014 and 2024, be written in English, involve human participants, and describe a measurement or intervention for anxiety, regardless of study design. No age limit was imposed in the search, and all levels of play were included. The review encompassed bibliographic databases, grey

literature databases, and other sources such as conference proceedings, theses, and dissertations. Articles without freely available full text, papers that did not specifically assess anxiety in women soccer players, or those that included mixed-gender group data or lacked gender data, non-player participants, studies on male soccer players, atypical development, female soccer referees, or anxiety topics in other women’s sports were excluded.

Record screening and data extraction

Records identified in the search were uploaded to the “Rayyan” [12] software to resolve potential duplicates. Two researchers (E.A.T and V.T.) reviewed the titles and abstracts of each paper against the eligibility criteria (e.g., wrong population, wrong outcome, other language, no freely available full text). After the initial screening, the full texts of the selected records were gathered and independently examined to ensure they met the eligibility criteria. Any disagreements between the reviewers were resolved by a third reviewer (G.T.). The results were then extracted, and a table was populated with the following data: author, year of publication, title, sample size and participant characteristics, type of instrument used in the research, and study results.

Data synthesis

The results were synthesized in accordance with the Guidelines, which provide a structured approach to combining qualitative and quantitative data [13]. This guidance specifically supports narrative synthesis in systematic reviews.

Results

The synthesis aimed to present the range of evidence that met the objectives of the scoping review. The search generated 5742 results. After deduplication, 2885 unique records remained. Of the 21 records read in full, 7 were excluded, and 14 met the inclusion criteria (Fig. 1). Data from the primary studies were initially presented in a tabular format as the starting point for the synthesis. The studies were then clustered based on characteristics in the data extraction tables, such as participants, sample size, instruments, and outcomes. The summary of these findings is presented in Table 1.

Table 1. Findings from the Literature Review

N°	Reference	Participants	Tools	Main findings
1	2	3	4	5
1	[15]	19 women soccer players	The Sports Motivation Scale The Anxiety Scale	Massage increased psychological stimulation and motivation, positively affecting situational anxiety.

Table 1. (Continued)

N°	Reference	Participants	Tools	Main findings
1	2	3	4	5
2	[16]	14 women soccer players	Heart rate monitor (Polar RS800CX, Finland) Competitive State Anxiety Inventory-2R (CSAI-2R)	The study underscores the value of using HRV as a measure of pre-competitive anxiety in semi-professional soccer players.
3	[17]	48 women soccer players	Sports Achievement Motivation Test (SAMT) Sports Competitive Anxiety Test (SCAT)	The findings indicate that professional female soccer players had moderate achievement motivation and highly competitive anxiety.
4	[18]	50 women soccer players	Sport Competition Anxiety Test (SCAT)	Significant reduction in anxiety levels with psychoneuromuscular theory and visualization techniques.
5	[19]	103 women soccer players	Generalised Anxiety Disorder Scale (GAD-7) Kessler-10 (K10) distress scale Centre for Epidemiological Studies Depression Scale (CES-D) SCOFF questionnaire	The prevalence of symptoms among semi-elite female footballers was 49.5% for distress; 44.7% for depression; 20.4% for generalised anxiety and 22.3% for an eating disorder.
6	[20]	43 women soccer players	Short Profile of Mood States (ISP) State-Trait Anxiety Inventory (STAI) Yo-Yo Intermittent Recovery [YYIR] test	YYIR-1 test showed significant changes in mood states and hormonal levels. State and trait anxiety correlated with cortisol and mood
7	[21]	8 women soccer players	State-Trait Anxiety Inventory (STAI) Incredibly Short Profile of Mood States (ISP) Cortisol (saliva sampling)	Significant relationships between cortisol levels and anxiety scores. The STAI questionnaire was useful in predicting cortisol surges.
8	[22]	52 women soccer players	DSR questionnaire BAI questionnaire HCYTOMAG-60K kit	PMS group had higher anxiety levels. IL-10 correlation varied with PMS status.

Table 1. (Continued)

N°	Reference	Participants	Tools	Main findings
1	2	3	4	5
9	[23]	13 women soccer players	Demographic Questionnaire Mental Readiness Form-3 (MRF-3) Rating Scale for Mental Effort (RSME) DELSYS Trigno Avanti Virtual Reality Head-Mounted Display (VR HMD) and Application Polar H10 sensor Pro Strap	VR significantly reduced cognitive and somatic anxiety, and improved self-confidence. 84.62% would use VR again
10	[24]	30 women soccer players	Sports Competition Anxiety Test (SCAT)	Significant anxiety differences between players from Manipur and Sikkim. Psychological conditioning recommended.
11	[25]	128 women soccer players	The Achievement Motive Scale—Sport (AMS-S) The Competitive Trait Anxiety-Questionnaire (CTA-Q) Competitive State Anxiety Inventory-2 (CSAI-2)	Somatic state anxiety was negatively associated with senior national team experience and positively associated with worry trait anxiety and fear of failure. Cognitive state anxiety was negatively associated with hope for success and positively associated with somatic and worry trait anxiety.
12	[26]	20 women soccer players	Competitive State Anxiety Inventory-2 (CSAI-2)	The study observed that moderate competition anxiety among women soccer players is associated with fluctuations and inconsistencies in their playing performance.
13	[27]	42 women soccer players	Competitive State Anxiety Inventory-2 (CSAI-2)	The anxiety levels among female elite soccer players vary between Manipur and Tripura. There are differences in anxiety levels between female elite football players in Manipur and Tripura

Table 1. (Continued)

N°	Reference	Participants	Tools	Main findings
1	2	3	4	5
14	[28]	16 women soccer players	Competitive State Anxiety (CSAI-2) VO2 Peak Testing Polar HR monitor	No significant differences in VO2peak with pre-performance anxiety; strong correlation between cognitive and somatic anxiety.

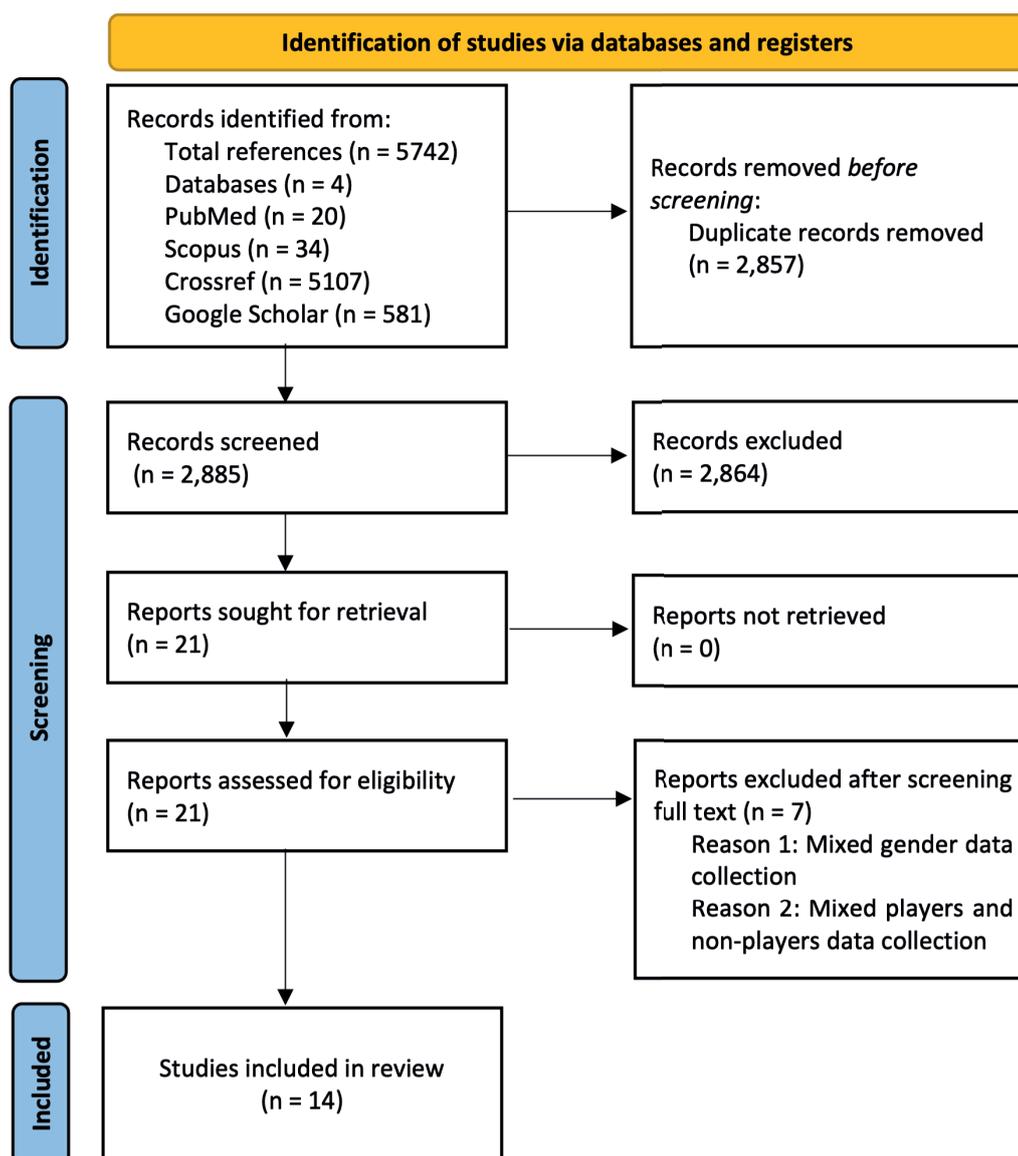


Figure 1. PRISMA Flow Diagram [14]

Discussion

The aim of this study was to map the evidence on anxiety in women’s football over the past decade and to identify interventions aimed at managing this anxiety among female soccer players. The review identified 14 studies that met the inclusion criteria, highlighting a range of psychological

interventions used to address anxiety in this population. These interventions exhibited varying levels of effectiveness, providing insight into current practices in anxiety management within women’s football.

Overview of Included Studies. The included studies, presented in Table 1, involved a sample

Table 2. Tools for Addressing Anxiety.

N°	Measurement Tools	Frequency	Author	Country
1	Competitive State Anxiety Inventory-2 (CSAI-2)	5	[16, 25, 26, 27, 28]	Spain, Denmark, India, United States
2	Sports Competition Anxiety Test (SCAT)	3	[17, 18, 24]	India
3	Heart Rate Monitor (Polar RS800CX, Finland)	1	[16]	Spain
4	DSR Questionnaire	1	[22]	Brazil
5	Beck Anxiety Inventory (BAI)	2	[22]	Brazil
6	Sports Motivation Scale	1	[15]	Turkey
7	Achievement Motive Scale—Sport (AMS-S)	1	[25]	Denmark
8	Mental Readiness Form-3 (MRF-3)	1	[23]	United States
9	Rating Scale for Mental Effort (RSME)	1	[23]	United States
10	Short Profile of Mood States (ISP)	2	[20, 21]	South Africa
11	State-Trait Anxiety Inventory (STAI)	2	[20, 21]	South Africa
12	Cortisol (saliva sampling)	1	[21]	South Africa
13	Generalized Anxiety Disorder Scale (GAD-7)	1	[19]	United Kingdom
14	Kessler-10 (K10) Distress Scale	1	[19]	United Kingdom
15	Centre for Epidemiological Studies Depression Scale (CES-D)	1	[19]	United Kingdom.
16	SCOFF Questionnaire	1	[19]	United Kingdom
17	Virtual Reality Head-Mounted Display (VR HMD)	1	[23]	United States

of 586 participants, all of whom were women soccer players. These studies were conducted in the following countries: India [17, 18, 24, 26, 27], the United Kingdom [16, 19], Denmark [25], the United States [23, 28], South Africa [20, 21], Turkey [15], and Brazil [22]. India had the highest representation with five studies, followed by the United States and South Africa with two studies each. The United Kingdom, Spain, Denmark, Turkey, and Brazil each had one study. This distribution underscores the need to diversify research efforts to develop a comprehensive understanding of anxiety in women’s soccer globally. The number of studies published by these countries may indicate higher levels of institutional support, funding, or awareness of mental health issues in female soccer within those regions.

Tools for addressing anxiety. The descriptions of the questionnaires or equipment used in the selected studies were divided into four separate cells to facilitate visual comparisons (Table 2). The Competitive State Anxiety Inventory-2 (CSAI-2) tended to be the most frequently used instrument in the studies presented. The second most commonly used assessment tool for measuring competitive anxiety in athletes in our scoping review was the Sports Competition Anxiety Test (SCAT).

In contrast, instruments like the Virtual Reality Head-Mounted Display (VR HMD) were used only once. This suggests that traditional anxiety measurement tools are preferred by the authors in our study and have been more prevalent in research over the last decade compared to modern technologies. This preference could be due to the familiarity, reliability, and validity of traditional instruments compared to newer, less-tested methods. Authors who used questionnaires for their studies were from India, Turkey, and the United Kingdom. Authors who used a mix of technologies and questionnaires to assess anxiety in female soccer players were from Spain, Brazil, the United States, and South Africa.

The integration of advanced physiological monitoring and biochemical analysis tools with anxiety assessment instruments over the past decade highlights a more precise and targeted approach by researchers in evaluating the mental health and performance of female football players. The United States appears to be leading in the use of the most advanced and diverse technological tools, indicating a strong emphasis on integrating high-tech solutions into research and practical application.

The incorporation of digital and mobile health

Table 3. Declared Study Limitations

Author(s) & Year	Research limitations
[15]	No limitations reported.
[16]	Small sample size. Follow-up data on HRV and pre-competitive anxiety not collected for all games. Physical load could affect results.
[17]	The study noted that the underdeveloped facilities, exposure, player payments, and infrastructure at Delhi's professional soccer clubs might have impacted the players' psychological traits.
[18]	No limitations reported.
[19]	Self-report measures may introduce bias, with severe cases possibly exaggerating symptoms.
[20]	No limitations reported.
[21]	Small sample size. More research needed to account for various player factors and validate findings.
[22]	Use of urine as a sample due to refusal of blood collection.
[23]	Small sample size. COVID-19 restrictions (face covering) may affect generalizability
[24]	No limitations reported.
[25]	The study acknowledges that the sample size of 128 players limits the generalizability of the findings. Variability in response rates and the potential for self-reported measures to reflect a more positive image of participants may affect the results.
[26]	No limitations reported.
[27]	No limitations reported.
[28]	Small sample size. Uncontrolled variables like caffeine, diet, and hydration may affect results. Not tracking playing time or adherence to off-season programs.

tools [29], wearable technology [30], physiological monitoring [31], neuroimaging [32], and biochemical analysis [33] could potentially make a significant difference in studying anxiety in women's soccer. These innovations might offer more accurate and real-time data on anxiety, enhance understanding of its impact on performance, and support more personalized and effective interventions. However, while these technologies hold promise, their effectiveness and practical applications need to be validated through further research and implementation.

Interventions effectiveness. Three of the 14 studies included experimental interventions with significant impacts on female soccer players' anxiety, highlighting their efficacy. One innovative approach involves Virtual Reality (VR), which immerses players in simulated environments to manage stress and anxiety. A study by Harrison et al. [23] indicated that VR could significantly reduce both cognitive and somatic anxiety, as well as overall stress, while potentially enhancing self-confidence and relaxation. Another potentially effective intervention is sports massage, as suggested by Abakay et al. [15]. Their research indicated that incorporating massage into pre-exercise warm-up routines might increase motivation and reduce situational anxiety. Additionally, techniques based on psychoneuromuscular theory and visualization appear to offer benefits. Borah and Yadav [18]

demonstrated that these methods could significantly reduce anxiety levels in players over a four-week training period. These interventions present promising strategies that might assist female soccer players in managing anxiety and enhancing their performance. However, caution should be exercised when generalizing the effectiveness of these interventions, considering the complexities of individual player experiences.

Limitations of the reviewed studies. The absence of reported limitations in several studies suggests either methodological robustness or a lack of thorough reporting (Table 3). Unacknowledged limitations can obscure the reliability of the findings and reduce the applicability of results across different contexts. Transparent reporting of study limitations is crucial for evaluating the validity of research and guiding future investigations [34, 35]. While the studies provide valuable insights into the prevalence and management of anxiety among female football players, the methodological limitations underscore the need for further research with larger sample sizes and more rigorous controls. This approach will enhance the generalizability and reliability of findings in understanding and addressing anxiety in female football players.

The scoping review of anxiety in women's soccer provides a comprehensive overview of the past decade's research on this topic. The review highlights a variety of methodological approaches,

with a small body of evidence suggesting that psychological interventions may be effective in managing anxiety among female soccer players. Traditional anxiety measurement tools were widely used; however, the adoption of newer technologies appears to be limited in this context.

This observation suggests a potential gap in integrating advanced technologies for anxiety assessment within women's soccer research. It is crucial to exercise caution when drawing definitive conclusions about the efficacy of interventions and the prevalence of measurement tools, given the complexities and individual variations within this research domain [36, 37, 38].

These findings underscore the need for continued exploration and the development of refined methodologies to study anxiety in women's soccer. A more comprehensive understanding of its impact on players' well-being and performance is essential and aligns with conclusions from other researchers and international institutions [39, 40, 41].

Although widely recognized digital databases such as PubMed, Scopus, Crossref, and Google Scholar were utilized for the search, it is important to acknowledge that the investigation may not have captured all relevant papers. Given the rapid advancements in this field, yearly updates will likely

be necessary as new research emerges. Additionally, any limitations of the software used, as noted by its authors, should be acknowledged.

Conclusions

This scoping review has provided a comprehensive overview of the existing research on anxiety in women's soccer over the past decade. While the evidence suggests that psychological interventions may be effective in managing anxiety among female soccer players, the adoption of newer technologies remains limited. The review highlights the importance of refining methodologies and broadening the scope of research to better understand the unique challenges faced by female athletes in this sport.

Given the rapid developments in this field, it is crucial to update research regularly to ensure that new insights and technological advancements are incorporated. Future research should focus on implementing controlled experimental interventions to identify effective strategies for supporting female soccer players. This could help in better understanding the gender-specific pressures associated with anxiety in women's soccer and managing the psychological load experienced by female football players. Discussing mental health does not impede performance.

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Ways to improve methods of monitoring the coordination abilities of young basketball players aged 13-14

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Abstract

Background and Study Aim

Coordination skills are an important indicator of success for young athletes in team sports. Therefore, the methods used to monitor these skills should include reliable and valid tests of coordination. The purpose of this study is to identify ways to improve the monitoring of coordination abilities in young basketball players aged 13–14 years.

Material and Methods

Basketball players aged 13–14 years participated in the study (n=35, training experience – 3–5 years). Twelve tests were used to assess the level of technical and tactical preparedness of the athletes. The reliability of these tests was evaluated by determining the correlation coefficients between the results of the first test and subsequent tests. The criteria for the informativeness of the tests were based on the experts' rank assessments of the coordination and technical preparedness of young basketball players. A 10-point scale was used for the expert assessment of players' technical skills, with each indicator evaluated from 1 to 10 points.

Results

The data obtained indicate that all selected tests demonstrated reliability with correlation coefficients above $r = 0.5$. Tests assessing muscle effort, adjusting motor activity, sense of rhythm, spatial orientation, and reaction speed showed reliability coefficients sufficient for both individual and group assessments ($r > 0.70$). Slightly lower reliability coefficients were observed in the time taken to perform individual motor tasks. The validity of the tests was evaluated based on ratings of coordination and technical readiness, as well as overall test battery ratings. In most cases, the validity was not lower than $r = 0.3$, with some tests exceeding $r = 0.5$. The correlation coefficient between grades and the total rank score based on the coordination test battery ranged from $r = 0.5$ to 0.7. The coefficient of concordance showed a high level of agreement among experts regarding the effectiveness of the technical and tactical actions of young basketball players.

Conclusions

The conducted study demonstrated the importance of developing and monitoring the coordination abilities of young basketball players during adolescence. The use of several homogeneous tests to assess each individual coordination ability allows for a more reliable evaluation. The need to identify specific types of coordination skills that play a key role in competitive basketball activities has been emphasized. Additionally, the use of a latent indicator in evaluating the coordination abilities of young basketball players will contribute to optimizing a differentiated approach in the training process.

Keywords:

basketball, players, coordination, abilities, methods, monitoring.

Introduction

Monitoring coordination abilities in team sports, including basketball, plays a key role in evaluating and improving athletes' performance. Effective monitoring allows coaches to track the development of essential skills and adjust training

programs accordingly. This requires refining existing approaches to ensure that the tests used are both reliable and valid.

In this context, one of the key tasks in sports games, and basketball in particular, is to assess the coordination readiness of young players [1, 2, 3]. According to the authors [4, 5], the development of methods and criteria for assessing coordination abilities is necessary to solve a number of interrelated scientific and applied problems. In particular, this

includes determining the level of coordination abilities in young basketball players, establishing the structure of these abilities in players of different ages, genders, and levels of preparedness. Equally important is determining the relationships between motor coordination indicators and physical qualities, technical preparedness, somatic indicators, and psychophysiological functions of basketball players. Moreover, a high level of coordination abilities is a prerequisite for selecting and orienting children towards basketball [6, 7, 8].

Of course, in different types of motor activity, separate tests are used to evaluate certain indicators of coordination preparedness. However, the standards related to sports games, qualification level, age, and gender are presented in a fragmented manner in the literature and do not cover all aspects of various types of coordination abilities. Additionally, in practice, complex tests are used more frequently than those focusing on specific types of coordination abilities. It is particularly challenging to assess the degree to which any specific type of coordination ability is manifested [9, 10].

Furthermore, such tests include elements of technical actions from various sports. These tests are convenient and easy to use for practitioners, making them quite common. However, according to [11, 12], this type of test is unsuitable for research purposes. The use of complex tests that include technical elements hinders the possibility of comparing the indicators of athletes from different sports, as each sport has its own specific tests. The results of testing with complex tests significantly depend on the athlete's qualification level and mastery of the technical arsenal. However, these tests do not purely reflect the level of coordination abilities. Moreover, it is known that the mechanisms responsible for different types of coordination abilities are ambiguous and often have little influence on each other. For instance, a high level of reaction speed does not necessarily imply the same level of ability to differentiate movement parameters, and so on. Thus, while using complex tests may provide a quick overall assessment of a player's coordination preparedness, it does not offer insight into the development of specific coordination abilities [13, 14, 15].

Clearly, the testing program for assessing coordination preparedness can and should include complex tests with elements of basketball technique, but it should not be limited to them. An important factor in developing the testing program is the appropriate selection of tests that evaluate different types of coordination abilities. In this regard, it is crucial to identify the most significant abilities for a specific sport and focus on assessing them during testing [16, 17, 18].

In addition to highlighting certain types of coordination abilities, when evaluating the coordination preparedness of young basketball

players, it is important to understand that there are basic coordination abilities [19, 20]. These abilities are largely determined genetically and form the foundation of all human activity (household, labor, sports, etc.). In the process of playing basketball, specific abilities are developed and manifested based on these general coordination abilities. This process continues throughout the entire period of long-term sports improvement.

It is clear that as the level of preparedness increases, the importance of specific coordination abilities also grows. This should be taken into account when assessing the coordination preparedness of young basketball players. Based on this, experts agree that at the stage of initial training, it is advisable to include only basic tests in the testing program. Subsequently, the proportion of basic and specific tests shifts towards the latter. Research on this topic indicates that in the training process of young basketball players who have achieved a high level of skill, 70% of the time spent assessing coordination preparedness should be dedicated to specific tests [21, 22].

The testing program allows you to determine the level of development of coordination abilities and, depending on the results, make necessary adjustments to the training process of young athletes at all stages of their long-term sports improvement. At the initial training stage, the coordination preparedness of young basketball players is usually assessed as a whole. However, as noted by Starosta [23], the need for individual evaluation increases as special preparedness grows. According to the researcher, athletes involved in a particular sport for a long time exhibit significant fluctuations in coordination ability indicators during the annual training cycle. Such strong variations in the results of the same player indicate that the mechanisms responsible for coordination abilities are influenced by internal and external factors. These factors presumably include fatigue, the stage of the annual cycle, time of day, season, mental state, etc. According to [24, 25], the amplitude of fluctuation in test results at different stages of the annual cycle is greatest in tests evaluating reaction speed, balance, and kinesthetic differentiation. This example highlights the potential for using coordination tests for the early diagnosis of fatigue and overtraining during basketball training.

Experimental studies by several authors have shown that one of the most effective ways to improve a player's technical and tactical skills is to purposefully develop various coordination abilities [26, 27]. In light of this, the authors sought to identify the key types of coordination abilities that have the most significant impact on achieving high results in basketball [28, 29, 30]. The coordination abilities that received the highest rankings include the ability to adjust movements, spatial orientation,

reaction speed, the ability to differentiate movement parameters, sense of rhythm, and dynamic balance.

Exploring different aspects of coordination qualities and associated psychophysiological functions in children, Ljach [31] found that the greatest increase in these indicators occurs between the ages of 7 and 11–12. In the later part of secondary school age, different coordination abilities evolve in a more differentiated and sometimes contradictory manner. After a decline between the ages of 12 and 13, boys aged 13 to 15 continue to improve the absolute indicators of coordination abilities in cyclic and acyclic locomotion, acrobatic exercises, and ballistic movements. According to Hirtz and Starosta [13], these growth rates are associated with parallel increases in strength and speed-strength qualities. While individual indicators of coordination abilities from ages 12 to 13 and 13 to 14 remain at the level of 12-year-old boys, in girls, they temporarily deteriorate. The optimal period for developing spatial orientation ability is in early adolescence. From 11 to 13 years, improvement in this ability slows somewhat, but from ages 13 to 15–16 (especially in boys), there is a further increase in performance.

Consequently, a contradictory situation has emerged between the need to improve the methodology for monitoring the coordination abilities of young basketball players aged 13–14 years, and the insufficient scientific development of methodological support to address this pedagogical problem. This highlights the practical and scientific relevance of the research problem.

Hypothesis. It is assumed that optimizing the methodology for monitoring the coordination preparedness of young basketball players will enhance the effectiveness of the training process. This approach will ultimately improve the players' performance in competitive activities.

Study purpose. The purpose of this study is to identify methods to improve the monitoring of coordination abilities in young basketball players aged 13–14 years.

Materials and Methods

Participants

Basketball players aged 13–14 years participated in the study ($n=35$, training experience – 3–5 years). Both the adolescents and their parents were fully informed about all study procedures, and written informed consent was obtained from both the players and their parents prior to participation. The study adhered to ethical standards in accordance with the Declaration of Helsinki, ensuring the participants' rights, safety, and confidentiality throughout the research process. The research protocol was reviewed and approved by the relevant institutional ethics committee.

Research Design

Based on a theoretical analysis, the types of coordination abilities that play a key role in the successful execution of basketball activities were identified. These include the ability to modify the motor program, rhythmic ability, reaction speed, spatial orientation, the ability to link phases of movement, dynamic balance, and kinesthetic differentiation. The tests we selected were verified according to the principles of motor quality testing theory and methodology. The reliability of these tests was evaluated by calculating the correlation coefficients between the results of the initial test and subsequent tests, conducted 7–14 days later (retest). The criteria for test informativeness were the coaches' rank assessments of the coordination and technical preparedness of young basketball players. In addition to absolute indicators of coordination abilities, relative indicators such as rhythmic ability, spatial orientation, and the abilities to couple and modify movements were also considered.

Test 1: The accuracy of estimating and measuring spatial movement parameters was assessed using a specially designed graduated screen. The player was given the task of reproducing the amplitude of 50% of a reference movement in the shoulder joint on the frontal plane. The movements were performed without visual control, using the player's dominant hand, with the shoulder joint positioned at the center of the graduated screen. During the study, the accuracy of the reproduced movements was not communicated to the player. The error was determined by comparing the reproduced movement value with the actual reference value. The average absolute value of the inverse proportion characterized the accuracy of the estimation and measurement of movement amplitude [32].

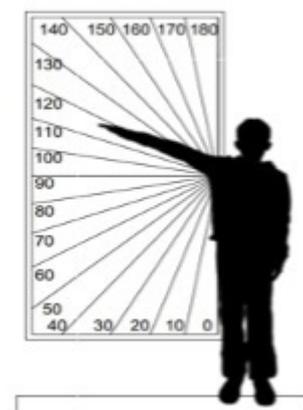


Figure 1. Determining the accuracy of estimation of spatial parameters of movements

Test 2: The accuracy of assessing and measuring the value of muscle effort was evaluated using a wrist medical dynamometer. While standing with the arm extended to the side, the player applied

maximum effort. In the following three attempts, the player was tasked with reproducing 50% of the maximum effort value. The inverse proportion of this task characterized the accuracy of assessing and measuring muscle efforts [33].

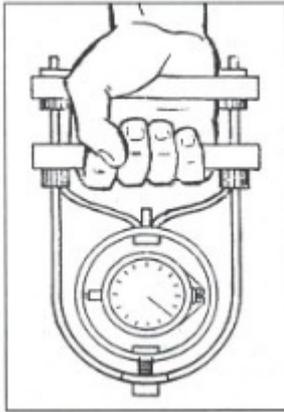


Figure 2. Determining of the accuracy of estimation of power parameters of movements

Test 3: “Slalom dribbling with two basketballs” [13]. *Equipment:* 3 cones, measuring tape, stopwatch, and basketballs. Three cones are placed in a straight line over a distance of 10 meters. The first cone is positioned 2.5 meters from the start line, with the remaining two cones spaced equally from each other. At the signal, the player runs the distance while basketball dribbling around the cones. The same task is then repeated, but with simultaneous dribbling of two basketballs. Instructions: Allow several minutes of rest between individual attempts.

Test 4: The time difference between performing a slalom while dribbling two basketballs versus one basketball.

Test 5: Balsom Agility Test [34]. This test measures both absolute and relative indicators of the ability to modify motor processes and speed. The test is performed both with and without basketball dribbling, and the difference between the two results is recorded. *Equipment:* stopwatch or timing system, ten cones. The cones are placed in pairs, two meters apart, with a line drawn between each pair. At a distance of 10 meters from the first pair “A” (starting line), pair “B” is placed, and 5 meters from “B,” the pair of cones forming the finish line is positioned. At a distance of three meters from the right cone of pair “A,” the left cone of pair “C” is placed (with the right cone two meters to the right). Pair “D” is placed 10 meters from pair “C.”

Test 6: Balsom Agility Test with basketball dribbling.

Test 7: The time difference between the Balsom Agility Test with and without basketball dribbling.

Test 8: “Sprint at the Given Rhythm Test with basketball dribbling” [35]. This test is used to measure rhythm ability. Eleven gymnastic hoops were systematically placed as shown in Figure 4.

The first three hoops were positioned next to each other, 5 meters from the starting line. Similarly, another three hoops were placed 5 meters from the finish line. The remaining five hoops were placed adjacent to each other in the middle of the running distance. The total distance from the start to the finish line is 30 meters. Additionally, two photocells were placed at the start and finish lines to measure the time. The test was demonstrated and explained to the participants before administration. The participants ran through the 11 hoops arranged at specific intervals, maintaining a set rhythm, and running at maximum speed, stepping between each hoop. They then repeated the task while basketball dribbling. The difference in time between the two attempts was recorded as the rhythm score.

Test 9: The time difference between the “Sprint at the Given Rhythm Test” and the “Sprint at the Given Rhythm Test with basketball dribbling.”

Test 10: “Numbered medicine ball run test (s)” [35]. This test is used to measure orientation ability. As shown in Figure 5, five medicine balls weighing 3 kg each, and one medicine ball weighing 4 kg were placed on the ground in the shape of a pentagon. The 4 kg medicine ball was positioned at the center of the base edge, while the 3 kg medicine balls were arranged around it. The distance between the 3 kg balls was 1.5 meters, and their distance from the center ball was 3 meters. Before the start of the test, the participants were asked to stand behind a photocell positioned right behind the six medicine balls, facing the opposite direction. At the signal, the participant turned from their starting position, crossed the photocell, and touched the 4 kg medicine ball. At that moment, the tester called out the number of one of the 3 kg balls, directing the participant to it. The participant touched the ball whose number was called, then ran back to the 4 kg ball, again facing the opposite direction. There was no need to stop after crossing the photocell. The tester immediately restarted the test, directing the participant to touch the 4 kg ball first, and then another numbered ball. This process was repeated five times in total. For the final repetition, the participant crossed the photocell to complete the test. Each participant had one practice trial before performing the actual test. The time taken to complete the test was recorded in seconds. The test was administered twice, and the better score was recorded.

Test 11: Time difference between the “Numbered medicine ball run test” and shuttle running (5×3 m), in seconds.

Test 12: “Stopping the rolling ball” [13]. Description: Two benches (with a 5 cm gap between them) are leaned against a shell-board at a height of 120 cm, allowing a volleyball to roll between them. A meter gauge is attached to the surface of one of the benches. The examiner holds the ball at the top of the gauge. The participant stands at a starting

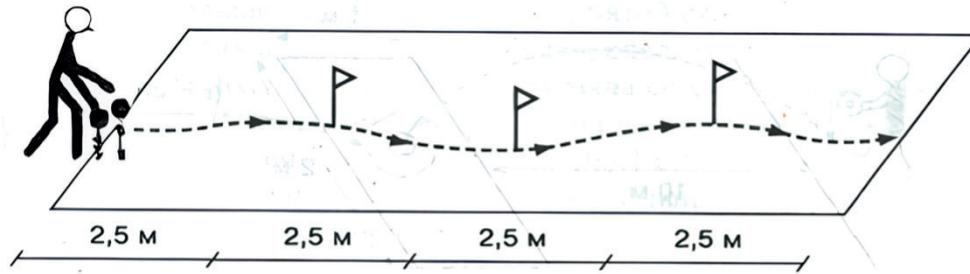


Figure 3. Slalom dribbling with two basketballs.

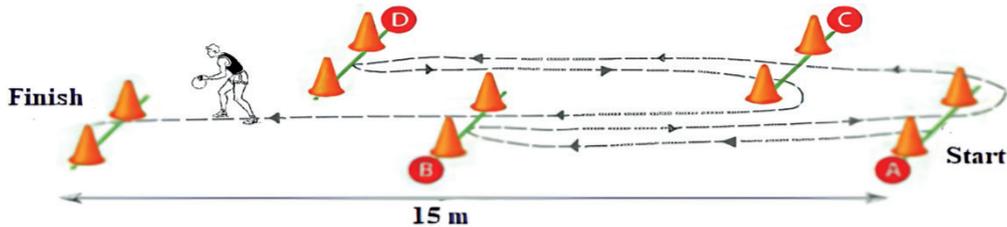


Figure 4. Balsom Agility Test with basketball dribbling.

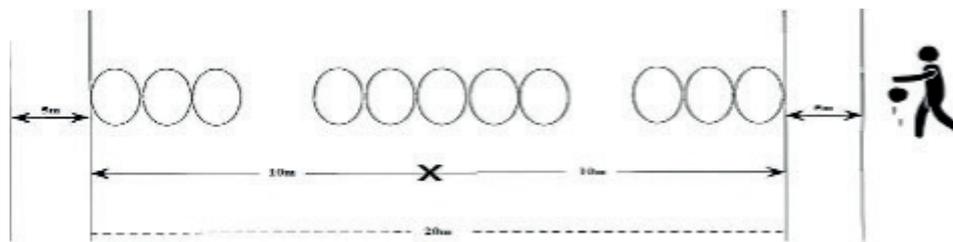


Figure 5. Sprint at the Given Rhythm Test with basketball dribbling.

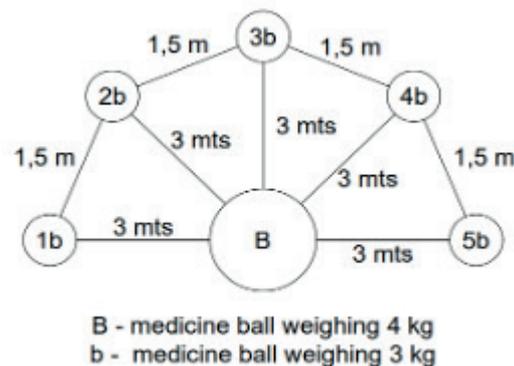


Figure 6. Numbered medicine ball run test

line, 150 cm from the lower edge of the benches, facing away from the ball (i.e., with their back to the rolling direction). At the examiner's audio signal, the ball is released to roll down the gap between the benches. The participant's task is to stop the ball with both hands as quickly as possible. There is one preparatory attempt and three measured attempts, with the best result being recorded.

Expert evaluation. Expert analysis of the technical and tactical preparedness of young basketball players was conducted by coaches with relevant experience.

This allowed us to determine the level of mastery of technical elements. The following components of technical preparedness were considered [5]:

- Amount of technique: The total number of technical elements used by the player during training sessions and game activities.
- Mastery of technique: Characterized by consistency (performance of technical elements in training conditions) and stability (performance of technical elements in competitive conditions).

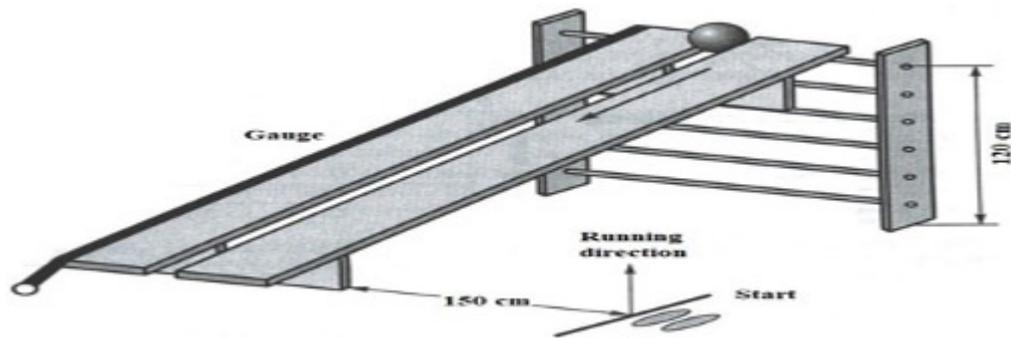


Figure 7. "Stopping the rolling ball"

- Efficiency of technique: Divided into absolute (the comparison of the basketball player's technique with reference parameters), comparative (comparison of the technique between players of different ages), and implementation (the degree to which technical potential is realized under competitive conditions).

For an expert assessment of the technical skills of players, a 10-point scale was used, in which each indicator was evaluated from 1 to 10 points. The total number of points scored by the player made it possible to determine the rating of their technical and tactical preparedness in the team aspect. To determine the consistency of respondents' opinions, the concordance coefficient was calculated.

Statistical analysis

Statistical data processing was carried out using Microsoft Excel and SPSS programs. The following parameters were determined for each indicator: arithmetic mean (\bar{X}), standard deviation (σ), error of arithmetic mean (m), coefficient of variation (V), correlation coefficient, χ^2 -criterion.

Results

The tests selected were verified in accordance with the theory and methodology of motor quality testing [36]. A test was considered reliable when the results achieved by the athletes during repeated testing after a short period of time were similar. The reliability of 8 tests and 4 indicators for assessing different types of coordination abilities in young basketball players was examined (Table 1). A reliability coefficient of $r = 0.5$ is considered sufficient for group diagnostics, while a coefficient of $r = 0.75$ or higher is required for individual diagnostics.

The data presented in Table 1 show that all selected tests demonstrate reliability above $r = 0.5$. It is advisable to highlight tests that assess coordination abilities such as the ability to evaluate and measure the magnitude of muscle effort (2), coupling movements (3), rebuilding motor activity (5, 6), sense of rhythm (8), space orientation (10), and reaction speed (12). The reliability coefficients

obtained for these tests are sufficient for both individual and group evaluations ($r > 0.70$). Slightly lower reliability coefficients are observed in the time differences for the execution of certain motor tasks.

The validity (diagnostic informativeness) of the selected coordination tests was determined using two criteria: rank assessments by coaches of the coordination and technical preparedness of young basketball players, and total rank assessments based on the battery of tests used. According to these criteria, most of the selected motor tests demonstrated a validity of no less than $r = 0.3$, with some exceeding $r = 0.5$ (Table 2).

An additional criterion for evaluating the diagnostic informativeness of the motor tests selected to assess coordination abilities was the correlation between the overall indicators of coordination preparedness of young basketball players and the subjective assessments of coaches. These assessments were based on the players' level of technical coordination capabilities and effectiveness in the game. The correlation coefficient between the coaching grades and the total rank score from the battery of coordination tests ranged from $r = 0.5$ to 0.7 .

To identify the values of expert assessments, the consistency of expert opinions was determined using Kendall's concordance coefficient [37]. The statistical significance of the concordance coefficient was assessed using the χ^2 test [37].

According to N. Bailey's table [37], the value of the χ^2 criterion was determined and compared with the calculated value of the χ^2 criterion to conclude the degree of consistency in the experts' opinions. The tabular value of χ^2 is 16.92 with a probability of error $p < 0.05$ and $V = 9$. Since the calculated χ^2 (31.4) exceeds the tabular χ^2 (16.92), a high degree of consistency in the experts' opinions can be confirmed.

Table 3 presents statistical indicators assessing various aspects of coordination preparedness in young basketball players. The data reveal consistent patterns in the players' coordination readiness. Variations are noticeable in areas such as accuracy, agility, and time management across different test

Table 1. Reliability coefficients of tests and indicators used to measure the coordination abilities of young basketball players

Coordination ability	Test, indicator	N	Retest for 7–14 days
Kinesthetic differentiation ability	The accuracy of estimation of spatial parameters of movements	1	0.62
	The accuracy of estimation of power parameters of movements	2	0.79
Ability of coupling (changing) movements	Slalom dribbling with two basketballs	3	0.69
	The time difference between performing a slalom with dribbling two and one basketball	4	0.50
Ability to rebuild movements	Balsom Agility Test	5	0.71
	Balsom Agility Test with basketball dribbling	6	0.66
	The time difference between Balsom Agility Test with and without basketball dribbling	7	0.52
Rhythmic ability	Given Rhythm Test with basketball dribbling	8	0.70
	The time difference between «Sprint at the Given Rhythm Test» and «Sprint at the Given Rhythm Test with basketball dribbling »	9	0.52
Space-orientation ability	Numbered medicine ball run test	10	0.80
	“Time difference between Numbered medicine ball run test and shuttle running (5× 3 m)”	11	0.57
Reaction speed	“Stopping the rolling ball”	12	0.82

Table 2. Diagnostic information of tests and indicators used to measure the coordination abilities of young basketball players

Coordination ability	Test, indicator	№	Criteria	
			1	2
Kinesthetic differentiation ability	The accuracy of estimation of spatial parameters of movements	1	0.40	0.33
	The accuracy of estimation of power parameters of movements	2	0.42	0.63
Ability of coupling (changing) movements	Slalom dribbling with two basketballs	3	0.55	0.87
	The time difference between performing a slalom with dribbling two and one basketball	4	0.42	0.68
Ability to rebuild movements	Balsom Agility Test	5	0.64	0.43
	Balsom Agility Test with basketball dribbling	6	0.92	0.79
	The time difference between Balsom Agility Test with and without basketball dribbling	7	0.52	0.63
Rhythmic ability	Given Rhythm Test with basketball dribbling	8	0.49	0.59
	The time difference between «Sprint at the Given Rhythm Test» and «Sprint at the Given Rhythm Test with basketball dribbling»	9	0.34	0.44
Space-orientation ability	Numbered medicine ball run test	10	0.31	0.85
	“Time difference between Numbered medicine ball run test and shuttle running (5× 3 m)”	11	0.40	0.36
Reaction speed	“Stopping the rolling ball”	12	0.62	0.80

parameters. Lower variability suggests that certain skills are more uniformly developed among the players. In contrast, higher variability indicates greater challenges with complex coordination tasks, like dual dribbling or rhythm-based activities.

Discussion

The aim of this study was to identify methods to improve the monitoring of coordination abilities in young basketball players aged 13–14 years. The results demonstrated that the selected tests reliably

Table 3. Statistical indicators of coordination preparedness of young basketball players

Nº	Indicator	\bar{X}	σ	m	V(%)
1	The accuracy of estimation of spatial parameters of movements, (°)	12.3	1.59	0.29	12.9
2	The accuracy of estimation of power parameters of movements, (kg)	3.1	1.03	0.19	32.3
3	Slalom dribbling with two basketballs, (s)	3.13	0.4	0.13	12.8
4	The time difference between performing a slalom with dribbling two and one basketball, (s)	0,52	0.16	0.03	31
5	Balsom Agility Test, (s)	11.3	0.77	0.24	6.3
6	Balsom Agility Test with basketball dribbling, (s)	12.03	0.81	0.26	6.8
7	The time difference between Balsom Agility Test with and without basketball dribbling, (s)	0.76	0.14	0.03	18.4
8	Given Rhythm Test with basketball dribbling, (s)	6.83	0.55	0.17	7.9
9	The time difference between «Sprint at the Given Rhythm Test» and «Sprint at the Given Rhythm Test with basketball dribbling», (s)	1.15	0.22	0.07	19.1
10	Numbered medicine ball run test, (s)	13.2	1.06	0.36	8.03
11	“Time difference between Numbered medicine ball run test and shuttle running (5× 3 m)”, (s)	2.1	0.48	0.09	22.9
12	“Stopping the rolling ball” , (cm)	89.3	5.5	1.01	5.7

assess various coordination abilities, with reliability coefficients exceeding $r = 0.5$ for all tests. Several tests, including those evaluating muscle effort estimation, movement coupling, motor activity adjustment, spatial orientation, and reaction speed, showed reliability sufficient for both group and individual diagnostics ($r > 0.70$). Additionally, the validity of the coordination tests was supported by significant correlations between test results and expert evaluations of the players’ technical and tactical preparedness.

An important step in monitoring coordination abilities is the development of data collection methods that provide more accurate and regular measurements. Among these methods is the use of computer programs, which allow the transfer of existing test procedures into digital formats and enable the measurement of indicators that were previously inaccessible. Recently, there has been significant expansion in the ability to collect information on various aspects of the preparedness of young basketball players. The use of computer programs makes it possible to transfer the test procedures available to researchers into their computer version, as well as to use indicators that were previously unavailable for measurement. The computerization of data collection about the state of the human body enables researchers to address tasks quickly, fully, in detail, and with greater accuracy. However, the use of scientific and methodological support remains fragmented and does not provide regular control in connection with the training process [38, 39, 40, 41].

As a result, it can be concluded that there are few methods for collecting and obtaining reliable information about the condition of young basketball

players that do not require significant expenses, yet still provide the necessary data. Therefore, a transition is needed to methods that minimize personnel and financial costs, while focusing on obtaining a carefully selected amount of reliable information [42, 43]. This transition can be achieved through the revision and modernization of existing approaches in youth basketball practice.

As shown in previous studies [44, 45], it is essential to identify weaknesses in the existing system of monitoring the coordination preparedness of young basketball players and update the normative evaluation criteria. It is also necessary to standardize these criteria as much as possible and harmonize them with the evaluation systems used in different countries. Moreover, having information about the coordination preparedness of young basketball players of various ages and the ability to compare this data with that of athletes from different countries allows for the identification of gaps in the training system. These insights enable necessary adjustments to increase the effectiveness of the training process.

One of the large-scale studies related to coordination preparedness in sports focused on football [46, 47, 48]. In these studies, the authors proposed nearly 20 tests to assess the level of development in areas such as rhythmic ability, balance, kinesthetic differentiation, movement adaptation, reaction speed, and spatial orientation. The researchers also recommended using these indicators as criteria for predicting the sports achievements of young football players.

A similar approach was applied in this study. In particular, each individual coordination ability was assessed using several homogeneous tests.

This approach provides a more reliable assessment of the development of each ability. Additionally, the positive correlations between homogeneous features indicate that these tests measure the same coordination ability. Moreover, care was taken to ensure that these tests were accessible to players of all ages and provided a differentiated assessment of the development of specific types of coordination abilities. It was also ensured that the tests did not involve complex motor actions that required extensive training or specialized equipment. The ability to perform control exercises with both the “dominant” and “non-dominant” limbs was considered to study the phenomenon of laterality (asymmetry) in relation to age and gender [49, 50].

In developing the criteria for assessing the coordination readiness of young basketball players, the focus was on evaluating the most significant types of coordination abilities for this sport. Similar views are expressed by other researchers [51, 52, 53, 54]. They note that when monitoring motor coordination at the stage of specialized basic training, the main emphasis should be placed on motor abilities critical for game performance. According to their findings, these include kinesthetic abilities (such as accuracy, timeliness, and adequacy of passes, throws, “feeling the ball,” and “feeling the basket”), the ability to adjust movements, spatial orientation, and reaction speed.

In this study, both absolute and latent (relative, partial) indicators of coordination abilities were used. The relative indicators did not account for the individual’s maximum speed, speed-power, and power qualities, but these were included in the absolute indicators.

Platonov and Nikitenko [55] offer a similar perspective on assessing the level of coordination preparedness of athletes. First, the authors recommend distinguishing between the concepts of “agility” and “coordination”. By agility, they refer to the ability to efficiently and accurately solve motor tasks in unexpected and difficult-to-predict situations. The element of surprise and ingenuity is key to defining this quality and the method of its testing. As for effective motor actions performed in various, even the most complex, but well-known conditions that are not unexpected or unpredictable, the authors suggest using the term coordination. In such cases, the test results are determined by the technical proficiency of motor actions and speed-power capabilities. When it comes to agility, the effectiveness of testing depends not only on technical and speed-power potential but also on the perceptual-visual capabilities of a basketball player, situational knowledge and experience, the ability to counteract, and pattern recognition. Therefore, the authors recommend using both open and closed tests to assess agility and coordination. Open tests are based on stereotypical movements. They are

conducted in a constant and stable environment with a familiar and proven program. These tests form the core of testing programs, as they have strict standards and regulations, ensuring measurement accuracy and the ability to compare results across different stages of testing. In contrast, tests built on a non-stereotypical (closed) program involve motor actions in a variable environment, with unexpected situations arising during the execution of test programs. Performing identical tests with both standard and variable structures allows for comparison of results and identification of factors that limit the effectiveness of motor skills and disrupt the training process for young basketball players. For instance, players with high movement speed but slow decision-making and delayed responses need to improve their perceptual abilities, while basketball players with quick responses and prompt decision-making but slower movement speeds should focus on speed and technical training [56].

Despite the positive outcomes of this study, there are several limitations that should be considered. First, the sample size was relatively small, which may affect the generalizability of the results to a broader population of young basketball players. Second, the study primarily relied on traditional testing methods, and while some computer-based assessments were suggested for future use, they were not integrated into the current research. Additionally, the study focused on specific coordination abilities, potentially overlooking other motor qualities that could influence performance.

Thus, theoretical analysis and experimental verification confirmed the possibility of using a wide range of tests to obtain sufficiently reliable assessments of the level of development of coordination abilities. The majority of this program should consist of control exercises that evaluate the most important types of coordination abilities in young basketball players. The use of relative indicators in assessing coordination abilities minimizes the influence of other motor qualities on test results. Additionally, further development of computer-based tests is needed to evaluate the coordination abilities of young basketball players. It seems that more attention should be given to assessing coordination abilities during gameplay, as the effectiveness of game actions is more than just the sum of isolated abilities and skills. The overall effectiveness of gaming activities should serve as the final criterion for evaluating the coordination preparedness of young basketball players.

Conclusions

1. The study highlighted the importance of developing and monitoring the coordination abilities of young basketball players during adolescence. This approach enables faster and more efficient mastery of new motor skills and

improves the technique and tactics of playing basketball. A high level of coordination ability development allows players to better handle tasks requiring psychophysiological functions in both the sensorimotor and intellectual domains.

2. Using multiple homogeneous tests to study each individual coordination ability allows for a more reliable assessment. The presence of positive correlations between homogeneous features indicates that this group of tests measures the same coordination ability.
3. When developing a testing program for assessing the coordination preparedness of young basketball players, it is advisable to use complex tests. It is also necessary to single out the types of coordination qualities that play a key role in

the competitive activities of basketball players. When assessing the motor coordination of players aged 13–14 years, it is important to focus on evaluating these specific abilities.

4. The use of a latent indicator in assessing the coordination abilities of young basketball players will contribute to optimizing a differentiated approach in the training process. Performing identical tests with both standard and variable structures allows for a comparison of results and helps identify factors that limit the effectiveness of motor skill development.

Conflict of interests

The authors declare that there is no conflict of interests.

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Investigation of the acute effect of different warm-up protocols on test performance in young soccer players

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

Abstract

Background and Study Aim Effective warm-up strategies are crucial for optimizing performance in team sports. However, identifying the most effective protocols requires consideration of the specific conditions and age of young athletes. The purpose of this study is to examine the acute effects of three different warm-up programs on specific test performance responses in young soccer players.

Material and Methods Twenty-three amateur soccer players (age = 15.13 ± 0.81 years) participated in the study. The athletes performed a dynamic warm-up along with two different neuromuscular warm-up programs: the FIFA 11+ and the Injury Prevention and Performance Enhancement Program. Performance responses in sprint, jump, and agility tests were measured. Data normality was assessed with the Shapiro-Wilk test. The effects of the warm-up protocols were analyzed using one-way repeated measures ANOVA, with significance set at $p < 0.05$.

Results The research findings revealed a statistically significant difference in the 10m sprint, 20m sprint, vertical jump, and zig-zag agility tests, both with and without the ball, when using the FIFA 11+ warm-up program ($p < 0.05$). The study demonstrated that the FIFA 11+ warm-up program improved performance responses more effectively than the other warm-up programs. This warm-up protocol enhances neuromuscular control by increasing the activation of the core, hip, and leg muscles.

Conclusions The study demonstrates that the FIFA 11+ warm-up program significantly enhances performance in specific tests, such as sprinting, jumping, and agility. Coaches are encouraged to implement the FIFA 11+ protocol in both training sessions and pre-match routines to optimize athletic performance in young soccer players.

Keywords: dynamic warm-up, FIFA 11+, soccer, agility, sprint

Introduction

Performance optimization remains a major challenge in youth soccer. High-intensity actions often result in fatigue and increase the risk of injury. Despite the widespread use of warm-up routines, there is still uncertainty about which protocols are most effective for enhancing performance and reducing injury risk. Soccer is among the team sports with the most significant sports population in the world in terms of both the number of spectators and participants [1], and it also attracts great interest among children and young people under the age of 18 [2]. Performance in soccer depends on technical actions such as shooting, passing, dribbling, and various physical factors such as sprinting, jumping, and changing direction [3, 4, 5]. Such high-intensity activities heavily burden the aerobic and anaerobic energy systems and impose many physiological demands [1]. The risk of injury increases due to the physiological responses in the muscles after high-intensity movements involving speed, agility, and explosive power [6]. Therefore, sports scientists and coaches must design effective warm-up programs before training or matches to maximize performance [7, 8].

Warming up involves short-term, high-intensity activities that improve physical fitness by increasing intramuscular temperature, nerve conduction velocity, and metabolic reactions [9]. In the literature, warming up is generally recognized to have two main effects: 1) maximizing performance [10, 11, 12] and 2) reducing the risk of injury [8, 13, 14]. Numerous studies have highlighted the effectiveness of different types of warm-ups under specific conditions [15, 16]. Research has shown that muscle performance can increase by 3.46% to 4.21% following a specific warm-up [9, 17]. This emphasizes the need for a well-defined pre-match warm-up, tailored to the players' characteristics, such as age, skill level, experience, and training hours.

Although various warm-up methods are used in soccer, programs like FIFA 11+ and the Injury Prevention and Performance Enhancement Program (PEP) are becoming increasingly common [10, 18]. These programs, preferred as alternatives to traditional warm-up methods, typically include running, static and dynamic stretching [19], neuromuscular exercises for injury prevention, high-intensity performance drills, post-activation exercises, and tasks aimed at specific tactical goals [20, 21]. The goal of these warm-ups is to transition

from general activities to more game-specific tasks to improve performance [22]. Consequently, several variables related to warm-up should be considered. For example, studies that examine factors such as the duration [12] and intensity [23] of the warm-up before performance suggest that a short warm-up (around 8 minutes) is the most effective in increasing acceleration. However, other research argues that both short-term and long-term warm-ups are equally effective for repeated sprint performance [16,24].

Thus, the FIFA 11+ and PEP programs have demonstrated significant effectiveness in improving various aspects of athletic performance. However, an analysis of the studies indicates that contradictions remain regarding the optimal duration and intensity of warm-ups. Despite this, few studies have directly compared these programs, especially among young athletes. This highlights the need for additional research to determine the most effective warm-up protocols under specific conditions. The purpose of this study is to examine the acute effects of three different warm-up programs on specific test performance responses in young soccer

Materials and Methods

Participants

The sample group consisted of 23 amateur male soccer players (age = 15.13 ± 0.81 years, height = 168.86 ± 6.78 cm, weight = 54.95 ± 7.54 kg, BMI = 19.18 ± 1.52) who had been training regularly for at least three years and were playing for the same club. The study was conducted during the preparation period at the beginning of the season, when no matches were scheduled. Before the study, each player was provided with detailed information about the potential risks and discomforts related to the research. The “Voluntary Subject Information and Consent Form” was read and signed by both the players and their parents. The study was conducted in accordance with the Declaration of Helsinki and was approved by the University Ethics Committee.

Research Design

First, anthropometric measurements were taken of the soccer players participating in the study. On the first day, the athletes performed the sprint, jump, and agility tests in sequence following the dynamic warm-up. On the second day, the same tests were conducted after the FIFA 11+ warm-up protocol. Finally, on the third day, the athletes performed the tests again after the PEP warm-up protocol. A 48-hour rest period was given between each testing day.

Data Collection Tools

Anthropometric Measurements. Participants’ height, body weight, and Body Mass Index (BMI) were measured using the Tanita BC 418 professional body analysis scale (Tanita Corp of America, Inc,

USA). Measurements were taken in the morning, with participants in anatomical posture, barefoot, wearing only shorts, and on an empty stomach.

10m-20m-30m Sprint Test. Sprint distances of 10, 20, and 30 meters were marked on the soccer field. Photocell devices with a precision of 0.01 seconds were placed at these points for accurate measurement. Each soccer player performed two attempts, and the best score was recorded.

Zig-Zag Agility Test. A photocell device with a precision of 0.01 seconds was placed at the designated start and finish points on the soccer field for measurement. The agility test was performed both with and without the ball. Each soccer player was asked to complete two attempts, and the best score was recorded.

Vertical Jump Test. For the vertical jump test, a Microgate WITTY (Wireless Training Timer, Bolzano, Italy) jump mat was used to measure the jump height of the soccer players. Players began with bent knees, jumped to reach the highest vertical point possible, and landed back on the mat. Each player performed two attempts, with the best score recorded.

Dynamic Warm-Up. The dynamic warm-up consists of four parts, lasting a total of 25 minutes. The first part includes a 10-minute warm-up run. The second part consists of 6 minutes of dynamic movements. The third part involves 6 minutes of static flexibility exercises, and the fourth part concludes with 3 minutes of tempo runs (Table 1).

Table 1. Dynamic Warm-up

EXERCISES	Time	Set
Section 1: Straight Running [Jogging]		
Straight Running	5 min	1
Section 2: Dynamic Warm-up Movements		
Arm Circles Forward, Arm Circles Backward, Hip Circles Clockwise, Hip Circles Counterclockwise, Legs Inward, Legs Outward, Knee-to-Chest, Heels to Glutes	6 min	1
Section 3: Static Flexibility Exercises		
Trapezius Stretch, Shoulder Rotator Cuff Stretch, Calf Stretch, Quadriceps Stretch, Hamstring Stretch, Adductor Stretch	6 min	1
Section 4: Pace Runs		
Sprints	3 min	1
Total	25 min	

FIFA 11+ Warm-Up Protocol. The FIFA 11+ warm-up program consists of three parts and includes 15 different exercises (Table 2). The first part involves

stretching and running exercises with controlled partner contact. The second part focuses on balance, trunk and leg strengthening, plyometric exercises, and agility drills. The third part consists of medium- and fast-paced running exercises, incorporating changes of direction [20].

Table 2. FIFA 11+ Warm-Up Protocol [11]

EXERCISES	Set	Repeat	Time
Section 1: Running Exercises			
Straight Running, Hip Outward, Hip Inward, Partner Exchange, Shoulder-to-Shoulder, Forward-Backward	2	1	8min
Section 2: Strength, Plyometric, and Balance Exercises			
Plank: Static Plank, Plank with Alternating Legs, Single-Leg Plank	3	1	20-30sec
Side Plank: Proper Position on Arm and Foot	3	1	20-30sec
Hamstring Stretch: Beginner (3-5 sec), Intermediate (7-10 sec), Advanced (12-15 sec)	1	3-5	60sec
Single-Leg Balance: Static Ball Hold	2	1	30sec
Squat: On Toes	2	1	30sec
Jump: Vertical Jump in Place	2	1	30sec
Section 3: Advanced Running Exercises			
Pace Runs, Bounding Runs, Zigzag Runs	2	1	2min
Total			20min

Injury Prevention and Performance Enhancement Program (PEP). The PEP warm-up program was developed to prevent lower extremity injuries [25]. It consists of five sections, lasts approximately 20 minutes, and includes exercises designed for muscle activation, balance, and trunk stability (Table 3).

Table 3. PEP Warm-up Protocol [25]

EXERCISES	Time / Repeat
1	2
Section 1: Warm-up	
Jog Line to line (cone to cone)	45.5 m
Shuttle Run	45.5 m
Backward Running	45.5 m

Table 3. (Continued).

1	2
Section 2: Flexibility	
Calf stretch	2 reps x 30 sec
Quadricep stretch	2 reps x 30 sec
Hamstring stretch	2 reps x 30 sec
Inner Thigh Stretch	2 reps x 30 sec
Hip Flexor Stretch	2 reps x 30 sec
Section 3: Strengthening	
Walking Lunges	2 set x 18 m
Russian Hamstring	30 sec
Single Toe Raises	30 reps on each side
Section 4: Plyometrics	
Lateral Hops over Cone	30 sec
Forward/ Backward Hops over cone	30 sec
Single Leg hops over cone	30 sec
Vertical Jumps with headers	30 sec
Scissors Jump	30 sec
Section 5: Agilities	
Forward run with 3 step decelerations	35 m
Lateral Diagonal runs	35 m
Bounding run	40 m

Statistical Analysis

Statistical analysis was conducted using SPSS version 26.0. Mean \pm standard deviation was used for descriptive analysis. The normality of the data was assessed using the Shapiro-Wilk test. The effects of the three different warm-up protocols on the performance tests were analyzed with a one-way repeated measures analysis of variance (ANOVA) for each performance variable. Statistical significance was set at $p < 0.05$. Effect sizes were evaluated using η^2 , where $0.01 < \eta^2 < 0.06$ indicates a small effect, $0.06 < \eta^2 < 0.14$ indicates a medium effect, and $\eta^2 > 0.14$ indicates a large effect [26].

Results

Table 4 presents the analysis results of the three different warm-up protocols. According to the results, there was a statistically significant difference between the groups in the 10m sprint, 20m sprint, vertical jump, and zig-zag agility tests, both with and without the ball. The FIFA 11+ warm-up protocol consistently showed better results compared to the PEP and dynamic warm-up methods.

Table 4. Warm-up protocols and Test performance results

Test performance	Warm-up protocols			p	η ²
	FIFA11+	PEP	Dynamic		
	$\bar{X} \pm SD$	$\bar{X} \pm SD$	$\bar{X} \pm SD$		
10m sprint	1.97 ± 0.10	2.00 ± 0.11	2.01 ± 1.0	0.000	.840
20m sprint	3.25 ± 0.13	3.28 ± 0.13	3.28 ± 1.13	0.000	.438
30m sprint	4.46 ± 0.22	4.48 ± 0.21	4.47 ± 0.21	0.215	.069
Vertical Jump	30.50 ± 4.77	30.21 ± 4.70	30.03 ± 4.72	0.007	.286
Zig-Zag Agility [with ball]	7.72 ± 0.26	7.73 ± 0.26	7.75 ± 0.27	0.016	.235
Zig-Zag Agility [without ball]	6.28 ± 0.14	6.32 ± 0.12	6.32 ± 0.15	0.000	.577

Note. \bar{X} : mean; SD: standard deviation; $p < 0.05$: significant value; η^2 : partial eta square value

Discussion

This study aimed to compare the acute effects of the neuromuscular warm-up protocols—FIFA 11+, PEP, and dynamic warm-up—on acceleration, sprint, jumping, and agility performances in male soccer players aged 14-16 years. The goal was to determine which of these warm-up methods is most effective in improving test performance times. The main finding of this study is that the FIFA 11+ warm-up protocol had a positive effect on 10m sprint, 20m sprint, vertical jump, and agility performances, both with and without the ball, in young soccer players.

There are numerous studies investigating the acute effects of dynamic, static, or combined warm-ups, which are commonly recommended to enhance athletic performance [19, 27, 28, 29]. Many of these studies have demonstrated that dynamic warm-ups have positive effects on performance [30], including improvements in sprint times [31], jump height [32], and agility [33]. For example, Needham et al. [34] examined the acute effects of three different warm-up protocols on anaerobic performance in young soccer players. These protocols included 5 minutes of low-intensity running followed by 10 minutes of either static stretching, dynamic stretching, or dynamic stretching combined with eight squats at 20% of body mass. Their findings showed that the dynamic warm-up protocol was more effective than the static protocol in improving anaerobic performance. These results align with recent studies, which suggest that dynamic stretching exercises in the warm-up phase enhance test performance compared to static stretching. Unlike static warm-ups, dynamic warm-ups are recommended as a pre-performance routine due to their acute enhancement of strength, sprint, and jumping performance [35]. However, there are relatively few studies that compare different dynamic warm-up methods while focusing specifically on physical performance. Most research in this area has concentrated on injury prevention programs, such as FIFA 11+ and PEP, rather than examining their direct effects on performance [10,36,37].

In this context, the results of our study align with previous research that highlights the positive effects of dynamic warm-ups on key performance indicators such as sprinting, jumping, and agility. Our findings, which demonstrate the effectiveness of the FIFA 11+ program, are consistent with those of Needham et al. [34] and Bizzini et al. [20], who also observed benefits from dynamic warm-ups in improving anaerobic and overall physical performance. However, unlike some other studies, such as the work by Impellizzeri et al. [43], our study observed more pronounced improvements in performance metrics following the FIFA 11+ protocol. This difference may be attributed to factors such as the age of the participants, the duration of the warm-up protocols, or other training-specific variables. Therefore, our study contributes to a deeper understanding of how different warm-up methods can impact the physical performance of young athletes.

In pre-performance warm-ups, various methods are applied to enhance key performance indicators such as speed, strength, and agility. Although the FIFA 11+ program was originally developed to prevent injuries, recent studies have shown that it can also improve the physical performance of soccer players [38]. Asgari et al. [10] conducted a systematic review that categorized the literature on the effects of the FIFA 11+ program into three main areas: performance, biomechanical measurements, and physiological responses. The first category includes studies on child players under 14 years old, the second focuses on adolescent and young players aged 14 to 20, and the third examines adult players over 20 years old. While the studies in the second category are most relevant to this study's sample group, the findings on performance parameters such as agility, vertical jump, balance, dribbling, and sprinting have been inconsistent.

Several studies have investigated the acute effects of different warm-up methods on speed, jumping, and agility test performances across various age groups. Two of these studies reported non-significant or even adverse immediate effects

on sprinting and agility when compared to dynamic warm-ups, which contrasts with the findings of our study [39, 40]. In contrast, Bizzini et al. [20] concluded that the FIFA 11+ warm-up method can be considered a suitable protocol, significantly improving speed and agility.

In comparison to previous research, our study's findings support the growing evidence that the FIFA 11+ program can positively impact physical performance, particularly in agility, sprinting, and jumping. While Asgari et al. [10] and other studies [39, 40] have reported inconsistent results, especially in young athletes, our study demonstrates clear benefits in these performance areas. Additionally, our results align more closely with those of Bizzini et al. [20], who observed significant improvements in speed and agility following the FIFA 11+ warm-up. The differences between these findings and those of earlier studies may be due to variations in participant age, training level, or the specific application of the warm-up protocols.

Similar to acute studies, chronic studies examining the effects of the FIFA 11+ warm-up protocol on performance responses have also shown conflicting results. When reviewing the sprint, vertical jump, and agility test performance responses in the literature, which are the performance parameters with significant differences in this study, there are studies that report positive effects of the FIFA 11+ warm-up protocol [38, 41, 42], as well as studies that show either negative effects or no effects at all [43, 44]. For example, Zarei et al. [42] reported that the FIFA 11+ program improved agility, vertical jump, and sprint performance among amateur U16 players during a soccer season. Similarly, Gok et al. [45] compared the effects of a general warm-up with the FIFA 11+ warm-up program on athletic performance and Functional Movement Screening (FMS) test scores in a study of 40 male soccer players aged 14-16. The group that followed the FIFA 11+ warm-up protocol showed improvements in 10m, 20m, and 30m sprint times, agility, vertical jump, balance, endurance, flexibility, and total FMS scores.

In contrast, Impellizzeri et al. [43] did not find similar results after applying the FIFA 11+ program to amateur players aged 21-25 over a nine-week period. However, this study aligns with recent research showing that the FIFA 11+ warm-up method enhances sprint performance [45], jumping performance [42], and agility [38]. This improvement is thought to result from the diverse components of the FIFA 11+ program, which combines various exercises such as balance, squats, and jumps. These exercises are believed to enhance neuromuscular control by increasing activation of the core, hips, and leg muscles. Additionally, the inclusion of exercises like the "Nordic hamstring curl" and plyometric drills may contribute to developing the stretch-shortening cycle, which is linked to

improved jumping performance.

In line with previous findings, our study confirms the positive effects of the FIFA 11+ program on key performance metrics, such as sprinting, agility, and vertical jump, as observed by Zarei et al. [42] and Gok et al. [45]. These results contrast with studies like Impellizzeri et al. [43], which reported no significant performance improvements after applying the FIFA 11+ program to older athletes. The conflicting outcomes across different studies may be explained by factors such as the age group of participants, the duration of the warm-up protocol, or differences in training environments. Our study reinforces the view that the multi-component nature of the FIFA 11+ program, including exercises like the Nordic hamstring curl and plyometrics, effectively enhances neuromuscular control and physical performance in younger athletes.

In comparison to existing studies, our research on the PEP protocol aligns with findings that demonstrate its limited impact on key performance outcomes, such as sprinting, jumping, and agility [47, 48]. While the PEP protocol has been effective in areas like dynamic balance and injury prevention, its influence on performance metrics remains inconsistent, as seen in previous studies. This contrasts with the more robust effects observed with the FIFA 11+ program, which has shown greater potential in improving physical performance across multiple tests. The relative lack of research on the PEP protocol, especially regarding its impact on athletic performance, suggests a need for further investigation to better understand its role in enhancing sports performance.

Some limitations of this study should be acknowledged. First, the study focused only on the acute effects of the different warm-up methods, without analyzing their chronic impact on performance outcomes. Additionally, the small sample size of participants is a limitation, and future research could benefit from including a larger group. It may also be advisable to conduct studies across multiple teams to increase the generalizability of the findings.

Conclusions

Some limitations of this study should be acknowledged. First, the research focused solely on the acute effects of different warm-up methods, without evaluating their long-term impact on performance outcomes. Additionally, the relatively small sample size limits the generalizability of the findings. Future studies should aim to include larger, more diverse participant groups and consider conducting research across multiple teams. This would provide a more comprehensive understanding of the effectiveness of these warm-up protocols and improve the applicability of the results for athletes in other sports games.

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Improving the physical components of gymnastics athletes following long-term circuit training with static and dynamic core stabilization

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Abstract

Background and Study Aim Core stability is a fundamental aspect of gymnastics performance, essential for balance, flexibility, and overall strength. This study aims to investigate the effects of long-term circuit training with static and dynamic core stabilization on physical components in gymnasts.

Material and Methods This study used a randomized controlled trial (RCT) design. A total of 42 participants were randomly assigned to three groups: a control group (CTR, n=14), a static core stabilization group (CSS, n=14), and a dynamic core stabilization group (CSD, n=14). The intervention programs for static and dynamic core stabilization included six distinct exercises. These exercises were performed three times per week over an 8-week period. Data were collected at two time points: pretest and posttest. Physical components assessed included flexibility, balance, and the strength of the abdominal, back, leg, and arm muscles. Data analysis was conducted using a paired sample t-test with the significance level set at 5%.

Results The results showed significant improvements in flexibility (cm), balance (s), back muscle strength (kg), abdominal muscle strength (repetitions), and arm muscle strength (repetitions) in the core stabilization groups between the pretest and posttest ($p \leq 0.05$). However, no significant changes were observed in leg muscle strength (kg) ($p \geq 0.05$). When comparing groups, significant differences were noted in balance (s), back muscle strength (kg), abdominal muscle strength (repetitions), and arm muscle strength (repetitions) ($p \leq 0.05$). Flexibility (cm) and leg muscle strength (kg) did not show significant differences between groups ($p \geq 0.05$).

Conclusions The study highlights the importance of incorporating core stabilization exercises into circuit training programs for gymnasts. Both static and dynamic approaches to core stabilization provide valuable strategies for optimizing physical conditioning and enhancing athletic performance. These findings can inform the development of evidence-based training protocols aimed at improving key physical attributes critical for gymnastics.

Keywords: core stabilization training, gymnastic, physical components, physical performance

Introduction

Gymnastics demands athletes to achieve exceptional levels of flexibility, balance, and muscular strength, all of which rely heavily on core stability. Despite the acknowledged importance of core-focused training, identifying optimal methods to develop these attributes remains a challenge, necessitating the search for more effective solutions. This pursuit is particularly critical in gymnastics, a sport that combines the demands of agility, strength, flexibility, and balance into a single, highly dynamic discipline [1]. Gymnasts are required to develop comprehensive abilities to integrate upper and lower extremity muscle strength, with core muscles

serving as the body's center of stability [2]. These core muscles, which encompass the muscles surrounding the spine, abdomen, lower back, and gluteal region, are crucial for maintaining postural balance and stability during dynamic and static movements such as flips, handstands, and landings [3]. Core strength and stability play a vital role in enhancing postural control and lumbopelvic stability, which are essential for ensuring biomechanical efficiency during complex gymnastics movements [4].

Core stabilization training is a method designed to improve core muscle strength and enhance body balance [5]. In gymnastics, core stabilization exercises are essential because movements such as longitudinal rotations, jumps, and landings demand dynamic postural stability to maintain balance [6]. These exercises, whether static or dynamic, improve stability by strengthening the trunk, abdominal, and

back muscles, which are critical for balance during activity [7]. Core stabilization training includes two primary components: static and dynamic movements [8]. Static exercises focus on maintaining posture under load, while dynamic exercises develop the ability to sustain stability during movements involving positional changes, rotation, or weight shifts [9]. Research has shown that combining static and dynamic core stabilization exercises significantly improves muscle strength, flexibility, and postural balance in athletes, which are key to enhancing gymnasts' physical performance [10].

The role of core muscles in injury prevention has been extensively highlighted in the literature. Golsefidi [11] emphasizes that regular core stabilization exercises enhance lumbopelvic stability, thereby reducing stress on the spine and lowering the risk of lower back injuries. Additionally, strong core muscles contribute to proper body alignment, ensuring more efficient force distribution between the upper and lower extremities during explosive gymnastics movements such as flips and landings [12].

Circuit training integrates various exercises into a single session to enhance muscle strength, endurance, and coordination [13]. Typically, it involves multiple stations that incorporate both static and dynamic core stabilization exercises, offering variety to sustain athletes' motivation while simultaneously strengthening core muscles, improving balance, and enhancing flexibility [14]. Exercises such as prone bridging on the elbow, supine bridge lifts with arms at the side, and dynamic hamstring stretches impose varied demands on the core, promoting increased strength and postural stability [15]. Moreover, circuit training that includes core stabilization exercises boosts neuromuscular capacity by strengthening the connection between the nervous system and muscles, leading to greater motor activation during contractions [16]. This is particularly critical in gymnastics, where complex movements like rotations and jumps demand rapid muscle responses to adjust posture and ensure precise control [11]. By integrating core stabilization into circuit training, athletes benefit from a diverse and comprehensive approach that improves motivation and supports overall physical performance development [17, 18].

The analysis of previous research highlights the importance of core stabilization in improving physical performance and preventing injuries in gymnastics. Studies show that both static and dynamic core stabilization exercises offer significant benefits. Integrating these exercises into circuit training has been found to enhance strength, balance, and flexibility. Additionally, circuit training improves neuromuscular coordination and reduces the risk of injury. However, the most effective methods for optimizing these benefits

remain unclear. This study aims to investigate the effects of long-term circuit training with static and dynamic core stabilization on physical components in gymnasts.

Materials and Methods

Participants

The study population comprised students from the Department of Sports Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya (Indonesia). Out of 140 available students, 42 were selected using random sampling techniques. These participants were assigned to three groups through ordinal pairing: a control group (CTR, n=14), a static core stabilization group (CSS, n=14), and a dynamic core stabilization group (CSD, n=14). The study followed a randomized controlled trial (RCT) design with a true experimental approach and a pretest-posttest control group format. Data were collected during both the pretest and posttest phases, measuring several physical components (Table 1).

Research Design

The static core stabilization program included six exercises:

1. Hip Flexor Stretch,
2. Prone Bridging on Elbow,
3. Prone Cobras,
4. Side Bridging on Elbow,
5. Supine Butt Lift Arm in Chest,
6. Prone Bridging Around the World with Parallel Hands.

The dynamic core stabilization program also comprised six exercises:

1. Dynamic Hamstring Stretch,
2. Prone Bridging on Elbow with Leg Extension,
3. Supermans,
4. Side Bridging on Elbow with Single Leg Hip Abduction,
5. Supine Butt Lift Arm at Side,
6. Prone Bridging Around the World with Cross Arm.

Both training programs were conducted three times per week over an 8-week period. Heart rate was monitored throughout the intervention using a Polar H10 heart rate monitor chest strap.

Statistical analysis

Descriptive statistics, including minimum and maximum values, means, standard deviations, and frequency distributions, were calculated to summarize the data. The Shapiro-Wilk test was used to assess data normality, while Levene's test was applied to evaluate homogeneity of variance. Hypothesis testing was conducted using paired sample t-tests and one-way ANOVA. Post hoc analyses were performed using least significant difference (LSD) tests to identify specific group

differences. The significance level was set at 5%. All statistical analyses were conducted using IBM SPSS Statistics V21.0 for Windows 10.

Results

The statistical analysis of the general characteristics between the static core stabilization

group (CSS) and the dynamic core stabilization group (CSD) showed no significant differences in any parameters ($p \geq 0.05$, table 2). Detailed results of the physical component analysis, including flexibility, balance, and strength of the abdominal, back, leg, and arm muscles, between the pretest and posttest are summarized in Table 3 and Figure 1.

Table 1. Summary of Variables, Instruments, and Tools

Parameters	Instrument Test	Unit	References
Balance	Balance Beam	second	[19]
Flexibility	Sit and Reach Test	cm	[20]
Abdominal muscle strength	Sit Up Test (30 s)	times	[21]
Back Muscle Strength	Back Dynamometer	kg	[22]
Leg Muscle Strength	Leg Dynamometer	kg	[22]
Arm Muscle Strength	Push Up Fitness Test (30 s)	times	[23]

Table 2. General characteristics of the participants

Parameters	CTR; n=14	CSS; n=14	CSD; n=14	p value
Age (yrs)	20.29 ± 0.83	20.28 ± 0.73	20.86 ± 0.87	0.110
Heart rate (bpm)	68.00 ± 8.88	72.36 ± 9.98	68.86 ± 9.82	0.450
Systolic blood pressure (mmHg)	116.57 ± 4.55	115.14 ± 7.36	114.29 ± 6.46	0.622
Diastolic blood pressure (mmHg)	81.57 ± 3.16	79.57 ± 8.38	79.29 ± 6.16	0.581
Body temperature (°C)	36.51 ± 0.39	36.60 ± 0.44	36.71 ± 0.43	0.451
Body weight (kg)	60.00 ± 5.59	59.14 ± 3.66	59.00 ± 5.12	0.217
Body height (cm)	168.00 ± 4.00	165.00 ± 3.00	167.00 ± 5.00	0.841
Body mass index (kg/m ²)	21.34 ± 1.28	21.74 ± 0.98	21.19 ± 0.77	0.352

Note. CTR: Control group; CSS: Core stabilization static group; CSD: Core stabilization dynamic group. The p values were calculated using one-way ANOVA. Data are presented as means ± SD.

Table 3. Comparison of gymnasts' physical components among the three groups

Parameters	CTR; n=14	CSS; n=14	CSD; n=14	p value
Pre-Flexibility (cm)	36.79 ± 8.25	37.79 ± 6.01	37.50 ± 3.21	0.908
Pre-Balance (s)	28.57 ± 23.11	23.00 ± 11.46	34.07 ± 26.72	0.402
Pre-Back Muscle Strength (kg)	96.24 ± 20.16	96.25 ± 19.71	98.04 ± 17.68	0.960
Pre-Leg Muscle Strength (kg)	101.33 ± 36.94	123.00 ± 30.56	117.11 ± 42.47	0.288
Pre-Abdominal Muscle Strength (times)	25.43 ± 2.98	24.43 ± 3.59	23.29 ± 4.07	0.295
Pre-Arm Muscle Strength (times)	28.57 ± 5.87	29.86 ± 7.89	28.79 ± 8.77	0.892
Post-Flexibility (cm)	37.36 ± 3.37	38.32 ± 6.04	39.79 ± 3.61	0.366
Post-Balance (s)	34.22 ± 26.65	31.43 ± 12.05	64.00 ± 41.82*†	0.010
Post-Back Muscle Strength (kg)	94.87 ± 22.77	111.50 ± 10.63*	106.93 ± 11.69*	0.025
Post-Leg Muscle Strength (kg)	112.93 ± 45.96	115.04 ± 17.98	126.07 ± 25.26	0.512
Post-Abdominal Muscle Strength (times)	23.22 ± 4.079	24.57 ± 2.96	26.86 ± 3.33*	0.028
Post-Arm Muscle Strength (times)	27.72 ± 9.86	35.07 ± 9.91*	36.72 ± 8.80*	0.039
Δ-Flexibility (cm)	0.57 ± 7.51	0.54 ± 3.16	2.29 ± 1.68	0.550
Δ-Balance (s)	5.65 ± 16.34	8.43 ± 8.10	29.93 ± 25.40*†	0.002
Δ-Back Muscle Strength (kg)	-1.37 ± 26.85	15.25 ± 15.99	8.89 ± 13.97	0.094
Δ-Leg Muscle Strength (kg)	11.60 ± 48.71	-7.97 ± 25.77	8.96 ± 32.93	0.328
Δ-Abdominal Muscle Strength (times)	-2.22 ± 4.69	0.14 ± 2.82	3.57 ± 2.62*†	0.000
Δ-Arm Muscle Strength (times)	-0.86 ± 8.68	5.22 ± 5.35*	7.93 ± 2.99*	0.002

Note. *Significant compared to CTR ($p \leq 0.05$); †Significant compared to CSS ($p \leq 0.05$). The p values were obtained using the least significant difference (LSD) post hoc test following one-way ANOVA.

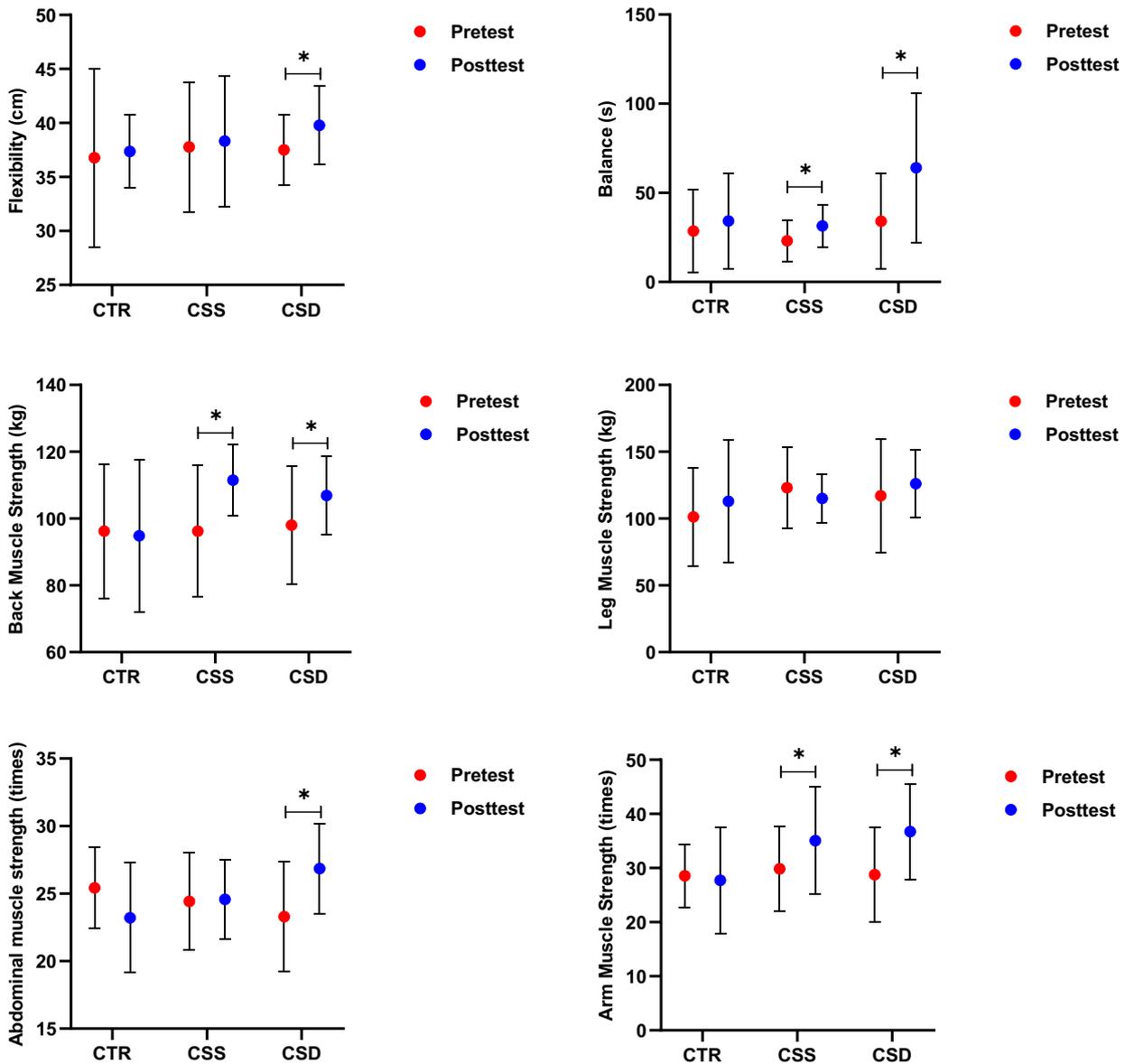


Figure 1. Comparison of gymnasts' physical components between the pretest and posttest in each group. Note. * indicates significance at the pretest ($p \leq 0.05$). The p value was obtained via paired sample t tests.

Discussion

The findings of this study show that incorporating static and dynamic core stabilization exercises into circuit training significantly enhances flexibility, balance, and the strength of key muscle groups, including the abdominal, back, leg, and arm muscles, in gymnasts. These improvements reflect the combined effects of neuromuscular activation and physiological adaptations, involving the targeted activation of type I and type II muscle fibers during static and dynamic exercises. Static exercises, such as prone bridging, improve isometric stability by engaging type I fibers. In contrast, dynamic exercises, like prone bridging with leg extensions, activate type II fibers, which are crucial for explosive strength in movements like flips and jumps [24, 25]. By integrating both approaches, this study addresses

a notable gap in the literature, as prior research has often focused solely on either static or dynamic exercises without examining their synergistic potential, especially in gymnastics contexts.

The enhanced lumbopelvic stability achieved through this combined training method improves force distribution between the upper and lower extremities. This is a critical factor for high-impact gymnastics movements such as jumps, flips, and rotations. Improved stability not only enhances performance but also reduces spinal pressure. This reduction addresses a major risk factor for lower back injuries, which are common in gymnasts [12, 26]. While earlier studies have highlighted the general benefits of core strength, this research makes a unique contribution. It directly links lumbopelvic stability to both performance enhancement and injury prevention, offering a dual benefit.

Furthermore, the dynamic exercises used in this study improve proprioception. This allows gymnasts to maintain balance during complex movements like landings and rotations. Enhanced proprioception increases technical precision and reduces the risk of injury. It does so by promoting better body alignment during high-speed maneuvers [18, 27]. Unlike previous studies focused on static balance or simple motor tasks, these findings provide new insights. They show how proprioceptive gains translate into sport-specific performance outcomes, particularly in gymnastics.

From a physiological perspective, this study highlights that core stabilization exercises stimulate mitochondrial adaptation in core muscle fibers. This adaptation enhances energy efficiency and improves endurance during repetitive, high-intensity routines. Such a mechanism ensures that muscles can sustain performance even under fatigue, a critical requirement in gymnastics competitions [28, 29]. These findings expand the understanding of the metabolic benefits of core training, an area that is still underexplored in the context of gymnastics-specific demands. By integrating physiological, neuromuscular, and proprioceptive benefits, this research underscores the holistic impact of combining static and dynamic core stabilization exercises in circuit training.

Despite the promising findings, this study has several limitations. The eight-week intervention period may have been too short to capture long-term adaptations in neuromuscular and biomechanical performance. Longitudinal studies suggest that extended training durations are necessary to fully realize these benefits [5]. Another limitation is the relatively small sample size of 42 participants. While sufficient for detecting short-term improvements, this limits the generalizability of the results to the broader gymnastics population. Future research should address these issues by including larger and more diverse samples. It should also incorporate advanced biomechanical analyses, such as measurements of spinal posture, body alignment, and muscle fascia thickness. These additions would provide a more comprehensive understanding of the training's effects.

The implications of this research are significant for both gymnastics training and rehabilitation practices. Incorporating core stabilization exercises into circuit training routines not only enhances flexibility, balance, and muscle strength but also introduces varied and challenging activities that help sustain athlete motivation [17, 18]. These exercises could be adopted as part of daily training regimens to build a foundation for long-term performance and physical health [3, 30, 31]. Moreover, they hold significant potential for clinical applications, as they could be adapted into rehabilitation programs for athletes recovering from lower back injuries, helping prevent recurrence and facilitating quicker

recovery timelines [32]. Unlike traditional weight training or plyometric exercises, this integrated approach enhances postural control and dynamic stability, making it particularly suited for the complex demands of gymnastics.

This study demonstrates that integrating static and dynamic core stabilization exercises in circuit training enhances postural stability, balance, and core strength in gymnasts. These findings contribute to a deeper understanding of effective training methods by highlighting the complementary benefits of static and dynamic approaches. The research provides a basis for refining gymnastics training programs to improve athletic performance and support long-term physical health.

Limitations of the Study

While the study provides valuable insights, several limitations should be noted. Although an eight-week intervention is a commonly accepted duration in training studies, longer-term research could help to capture potential adaptations that may emerge over extended periods of training. Additionally, while the sample size of 42 participants meets the requirements for robust statistical analysis, future studies with larger and more diverse participant groups could further validate the findings and increase their applicability to broader gymnastics populations. Finally, the study did not incorporate advanced biomechanical assessments, such as analyses of spinal posture or muscle fascia characteristics, which could offer a more detailed understanding of the observed performance improvements. Addressing these aspects in future research could provide a more comprehensive evaluation of the effects of combined static and dynamic core stabilization training.

Conclusions

Integrating static and dynamic core stabilization exercises into circuit training represents a promising approach for enhancing the physical capabilities of gymnasts. This comprehensive method supports the simultaneous development of key physical attributes, meeting the specific demands of gymnastics. By combining the benefits of both exercise types, it establishes a foundation for effective adaptation within the training process.

This study contributes to the understanding of training methods aimed at improving functional performance and preventing injuries. The findings may serve as a valuable resource for coaches, sports physicians, and rehabilitation specialists in designing individualized programs that focus on the long-term development and health maintenance of athletes.

Conflicts of Interest

The authors declare no conflict of interest in this study.

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Effects of short-term high-intensity exercise on oxidative stress and antioxidant levels in healthy young males

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

Abstract

Background and Study Aim High-intensity interval training (HIIT) has become a popular exercise choice for people who have limited time but aim to maximize their workout results. This study aims to compare the impacts of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males.

Material and Methods The study included 30 healthy male adolescents aged 20–23 years who participated in HIRIT and HIPRT interventions over a four-week period. Data were collected by measuring levels of Malondialdehyde (MDA) and Superoxide Dismutase (SOD) as biomarkers of oxidative stress and antioxidants. These measurements were obtained before and after the intervention using Colorimetric Assay Kits. Data analysis was performed using paired sample t-tests and independent sample t-tests with a significance level set at 5%.

Results The results showed a significant decrease in MDA levels in both high-intensity training interventions. However, SOD levels increased significantly only in the high-intensity running interval training group ($p \leq 0.05$). Additionally, comparisons between groups revealed a reduction in MDA levels and an increase in SOD levels ($p \leq 0.05$).

Conclusions These findings suggest that both high-intensity running interval training and high-intensity progressive resistance training, conducted over a four-week period, are effective in reducing oxidative stress. Additionally, both types of training increase antioxidant levels in healthy young men. However, high-intensity running interval training proved to be more effective in reducing MDA levels and increasing SOD levels.

Keywords: antioxidants, oxidative stress, progressive resistance training, running interval training

Introduction

High-intensity interval training (HIIT) has become increasingly popular as an efficient workout option for individuals seeking significant fitness benefits within a limited timeframe. Despite this popularity, identifying the most effective HIIT methods for promoting physiological benefits in young, healthy individuals remains essential and continues to be an important focus in the search for new, optimized training solutions.

In this context, high-intensity interval training (HIIT) has proven to be highly effective for improving cardiovascular fitness and muscle strength within a relatively short period [1]. HIIT consists of short bursts of high-intensity physical activity interspersed with brief recovery phases [2]. This structure not only enhances the efficiency of

each session but also enables substantial fitness gains in less time compared to traditional training methods [3]. As a result, HIIT is an appealing option for individuals with limited time who still aim to maximize their fitness outcomes [4].

HIIT operates by pushing the body to reach or approach its maximum capacity during high-intensity intervals, thereby increasing oxygen consumption and boosting metabolism even after the workout ends [5]. This effect, known as excess post-exercise oxygen consumption (EPOC) or the “afterburn effect,” enhances calorie burn and metabolic rate post-exercise [6]. While HIIT is well-established in improving physical performance, its impact on oxidative stress, specifically on biomarkers like Superoxide Dismutase (SOD) and Malondialdehyde (MDA), remains a subject of ongoing debate in the scientific community [7]. SOD, a critical antioxidant enzyme, shields the body from oxidative damage induced by reactive oxygen species (ROS), whereas MDA serves as an indicator of lipid peroxidation

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and cellular damage [8]. Although numerous studies highlight the fitness benefits of HIIT, the exercise's precise effects on oxidative stress need further exploration, particularly concerning the molecular mechanisms that regulate ROS production and the body's antioxidant response [9].

Oxidative stress occurs when the production of reactive oxygen species (ROS) surpasses the capacity of the body's antioxidant systems to neutralize them [10]. This imbalance can lead to extensive cellular damage, including lipid peroxidation, with Malondialdehyde (MDA) as one of its byproducts [11]. Superoxide Dismutase (SOD), the primary antioxidant enzyme, plays a critical role in neutralizing ROS, particularly superoxide radicals, by converting them into hydrogen peroxide, which is subsequently broken down by other enzymes like catalase [8]. High-intensity exercises, such as HIIT, are known to increase ROS production, primarily due to heightened oxygen consumption during intense phases [12, 13]. However, the long-term effects of HIIT on the body's antioxidant capacity remain incompletely understood.

ROS production during HIIT varies based on the type of exercise performed [14, 15]. In aerobic-based HIIT running, the increase in oxygen consumption within the mitochondria during high-intensity phases leads to elevated ROS production [16]. The body adapts by boosting SOD activity through pathways such as Nrf2 (Nuclear factor erythroid 2-related factor 2) and PGC-1 α (Peroxisome proliferator-activated receptor gamma coactivator 1-alpha), which also promote mitochondrial biogenesis [17]. These adaptive pathways enhance the body's overall antioxidant capacity, making HIIT running more effective in stimulating antioxidant responses compared to other training methods [18].

In contrast, HIIT strength training, which emphasizes resistance and muscle strength, causes more pronounced mechanical damage to muscle fibers [19], resulting in localized ROS production in the affected areas [17, 20–21]. This can lead to lipid peroxidation, with MDA serving as a marker of cellular damage [22]. Although the body responds by increasing SOD activity [23–24], this response typically occurs more slowly compared to HIIT running, as the body prioritizes muscle tissue repair [25]. Consequently, MDA levels tend to be higher in the early stages of HIIT strength training, especially before full physiological adaptation has taken place [16, 26].

Although HIIT is widely recognized as an effective method for improving cardiovascular fitness and muscle strength, debate persists regarding its effects on oxidative stress and the body's antioxidant balance [1, 7]. Some studies indicate that HIIT running is particularly effective at enhancing antioxidant enzymes like SOD, which help protect the body from oxidative damage

induced by ROS [12, 16, 27, 28, 29]. In contrast, HIIT strength training often leads to elevated MDA levels due to increased muscle damage, suggesting a higher risk of cellular damage during the initial phases of training [30, 31, 32, 33]. This ongoing debate raises important questions about which type of HIIT is more advantageous for managing oxidative stress and whether the short-term risk of cellular damage is balanced by the body's long-term antioxidant adaptation.

This study aims to compare the impacts of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males.

Materials and Methods

Participants

This study used a true experimental design with a pretest-posttest control group structure. A total of 30 healthy males, aged 20–23 years, were recruited from university students in Malang and assigned to either high-intensity running interval training (HIRIT) or high-intensity progressive resistance training (HIPRT). The control group (CNTLR) did not receive any training intervention. Before the study began, all participants were informed verbally and in writing about the research procedures, and they provided consent to participate by signing an informed consent form. All study procedures were approved by the Ethics Committee of Universitas Negeri Malang [No.4.07.2/UN32.14.2.8/LT/2024], and the study adhered to the principles of the Declaration of Helsinki regarding ethical conduct in research involving human subjects.

Research design

High-intensity training programs

The high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) programs were implemented and supervised by professionals from the Department of Sports Science, Faculty of Sports Science, Universitas Negeri Malang. Participants were randomly assigned to one of three groups: a control group without intervention ($n = 10$), a high-intensity running interval training group ($n = 10$), and a high-intensity progressive resistance training group ($n = 10$). The HIRIT intervention consisted of sessions lasting 30–60 minutes, with participants performing 4–6 sets of 10–12 repetitions and taking active rest breaks of 30–60 seconds between sets. The HIPRT intervention was performed at an intensity of 80–90% of one repetition maximum (1RM), also in 4–6 sets of 10–12 repetitions, with active rest periods of 30–60 seconds between sets. Both training programs were conducted three times a week over a four-week period.

Data collection

Data were collected by drawing 4 ml of blood from the cubital vein before and after the intervention to assess serum SOD and MDA levels. MDA levels were measured using Human Colorimetric Assay Kits (TBA Method) (Cat. No.: E-BC-K025-M; Malondialdehyde (MDA); Elabscience Biotechnology Inc., Houston, TX, USA), while SOD levels were measured with Human Colorimetric Assay Kits (Cat. No.: E-BC-K019-S; SOD; Elabscience Biotechnology Inc., Houston, TX, USA). Additionally, participants' age, height, body weight, body mass index (BMI), systolic and diastolic blood pressure, resting heart rate, oxygen saturation, and body temperature were evaluated before the intervention.

Statistical analysis

Data analysis included a normality test using the Shapiro-Wilk test to assess the normal distribution of the data, and homogeneity was evaluated with Levene's Test. Data that were normally distributed with homogeneous variances were analyzed using parametric tests, specifically one-way ANOVA, followed by Tukey's HSD post-hoc test at a 5% significance level. All statistical analyses were conducted using SPSS version 23.

Results

The results showed no significant differences in the characteristics of the research subjects among the three groups, as detailed in Table 1. All characteristic parameters of the research subjects showed no significant differences ($p \geq 0.05$). Changes in SOD and MDA levels, which represent oxidative stress and antioxidant biomarkers, were analyzed between pre-training and post-training in each group: control (CNTLR), high-intensity running interval training (HIRIT), and high-intensity progressive resistance training (HIPRT). These results are presented in Figures 1 and 2.

The results showed a significant decrease in MDA levels between pre-training and post-training

in the HIRIT group (255.00 ± 77.42 to 141.50 ± 49.66 nmol/mL, $p = 0.000$) and in the HIPRT group (257.75 ± 28.98 to 166.50 ± 16.29 nmol/mL, $p = 0.000$). In contrast, no significant change in MDA levels was observed in the CNTLR group (273.50 ± 165.45 to 271.25 ± 128.17 nmol/mL, $p = 0.953$) (Figure 1).

SOD levels increased significantly between pre-training and post-training in the HIRIT group (75.19 ± 9.83 to 86.15 ± 5.99 nmol/mL, $p = 0.015$). However, no significant changes in SOD levels were observed in the CNTLR group (76.69 ± 9.94 to 75.59 ± 6.31 U/mL, $p = 0.816$) or the HIPRT group (75.38 ± 3.38 to 78.43 ± 8.72 nmol/mL, $p = 0.273$) (Figure 2).

Comparisons of SOD and MDA levels between the groups are presented in Figures 3 and 4.

Discussion

This study aimed to compare the effects of high-intensity running interval training (HIRIT) and high-intensity progressive resistance training (HIPRT) on oxidative stress biomarkers and antioxidant levels in healthy young males. The results show that both types of training effectively reduced oxidative stress and increased antioxidant activity in healthy adolescents. HIRIT proved to be more effective in increasing Superoxide Dismutase (SOD) levels. This enzyme plays a critical role as an antioxidant. HIRIT also reduced Malondialdehyde (MDA) levels, which is a marker of lipid peroxidation and cellular damage. In contrast, HIPRT caused a larger increase in MDA levels. This suggests greater cellular damage during the early adaptation phase of resistance training.

These findings align with the literature, which suggests that aerobic-based exercises, such as HIIT running, are more effective in enhancing the body's antioxidant activity compared to resistance training. Powers et al. [15] demonstrated that aerobic exercise increases SOD levels through molecular adaptation pathways. This includes the activation of Nrf2, a key regulator of antioxidant gene expression. During aerobic exercise, increased oxygen consumption in the mitochondria elevates the production of

Table 1. General characteristics of the research subjects

Parameters	Groups (Mean ± Std. Deviation)			p-value
	CNTLR (n=10)	HIRIT (n=10)	HIPRT (n=10)	
RHR (bpm)	71.60±4.86	70.20±4.76	69.30±5.25	0.585
SpO ₂ (%)	97.90±0.99	97.50±1.08	97.80±1.14	0.689
SBP (mmHg)	118.60±2.55	118.10±4.79	116.00±4.29	0.319
DBP (mmHg)	76.00±3.77	75.50±7.71	71.60±6.12	0.227
BT (°C)	36.40±0.22	36.30±0.19	36.26±0.21	0.303
BW (kg)	65.65±11.55	59.90±8.83	58.20±3.39	0.148
BH (m)	1.69±0.07	1.66±0.03	1.68±0.06	0.492
BMI (kg/m ²)	22.89±3.21	21.66±2.79	20.61±0.87	0.146
Age (years)	19.50±2.27	19.20±0.92	18.20±0.63	0.842

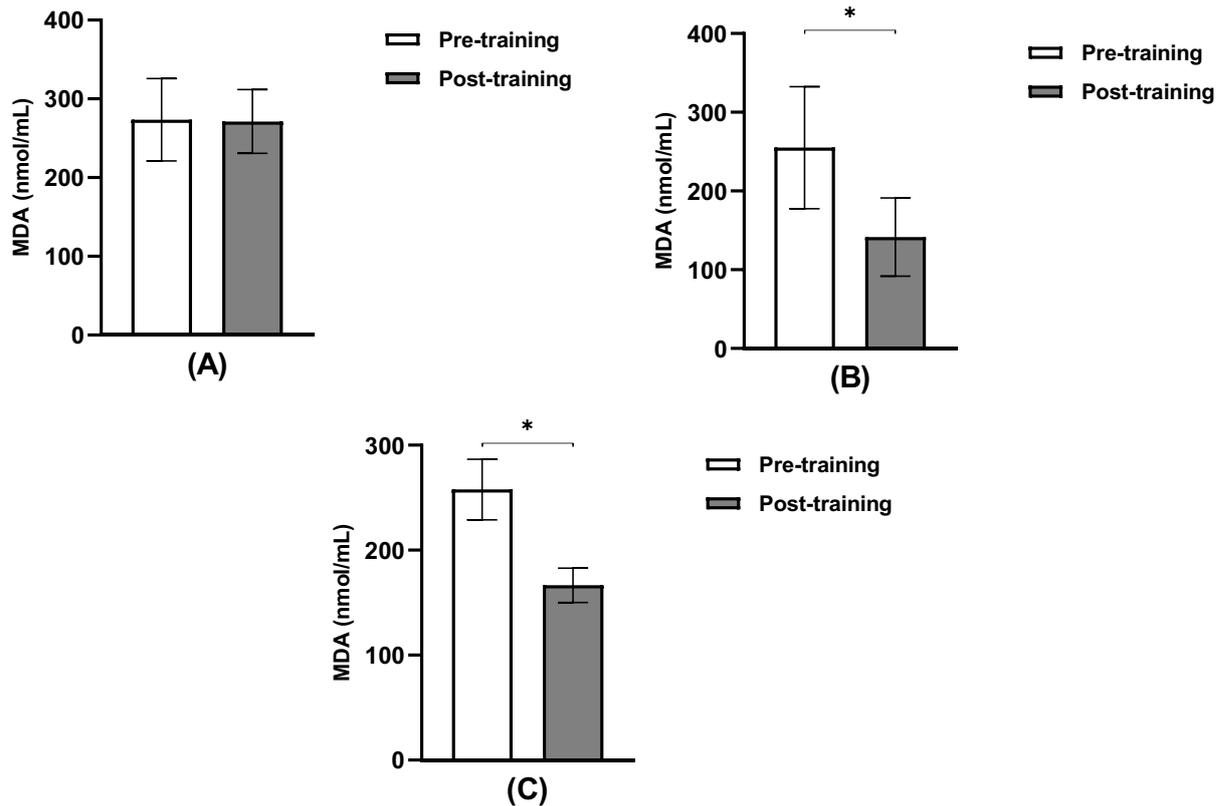


Figure 1. Differences in MDA levels between pre-training and post-training in the three groups. *Note.* (*) Indicates a significant difference from pre-training ($p \leq 0.05$). (A) Control group (CNTLR), (B) High-intensity running interval training group (HIRIT), (C) High-intensity progressive resistance training group (HIPRT).

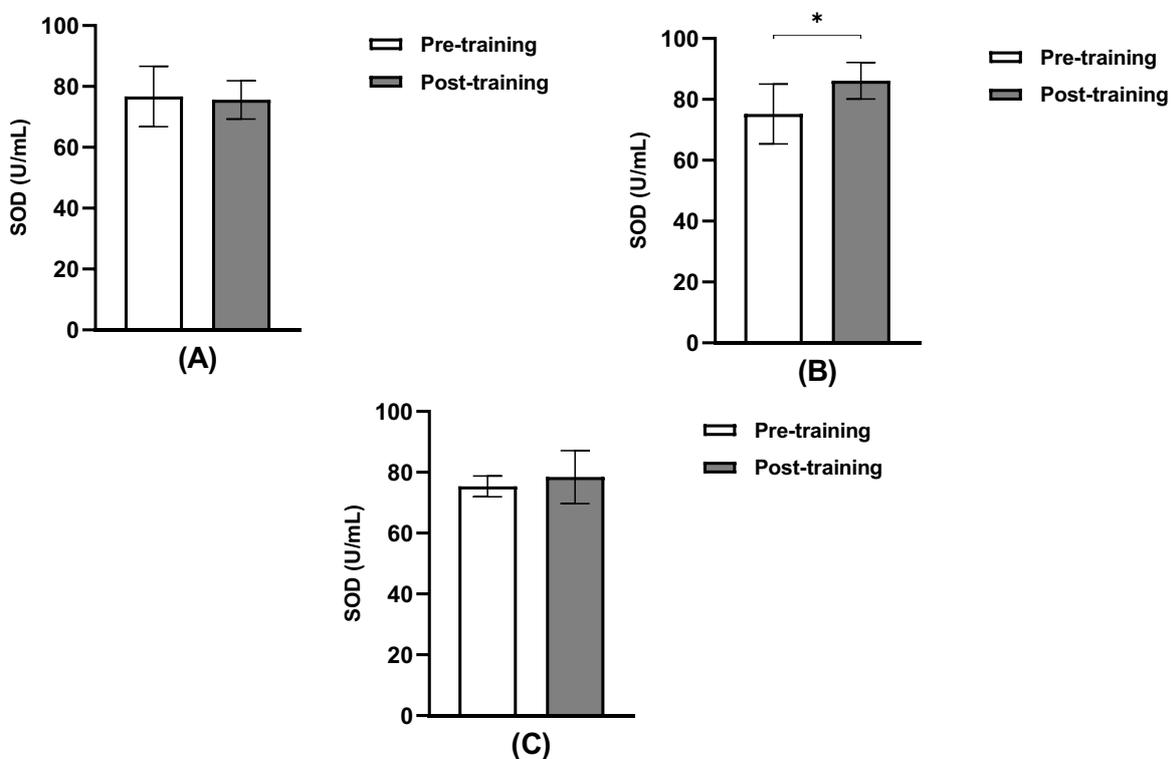


Figure 2. Differences in SOD levels between pre-training and post-training in the three groups. *Note.* (*) Indicates a significant difference from pre-training ($p \leq 0.05$). (A) Control group (CNTLR), (B) High-intensity running interval training group (HIRIT), (C) High-intensity progressive resistance training group (HIPRT).

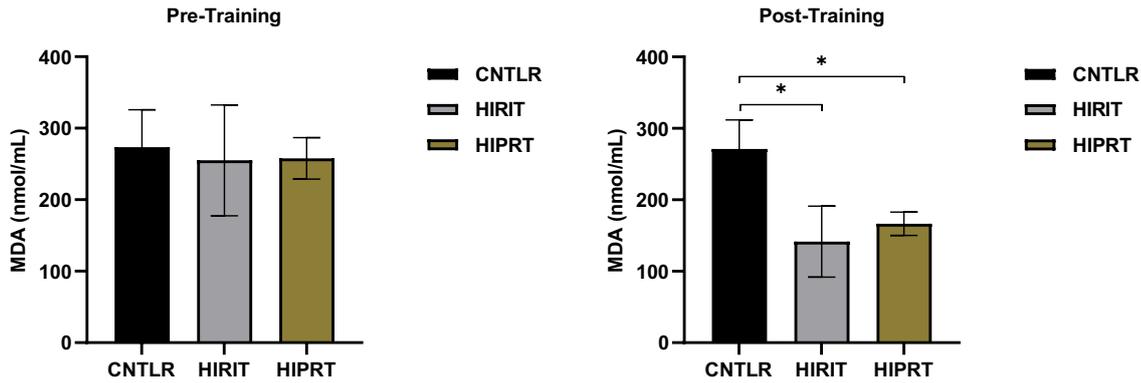


Figure 3. Differences in average MDA levels (nmol/mL) between groups. Note. (*) Indicates a significant difference from the control group (CNTLR) ($p \leq 0.05$).

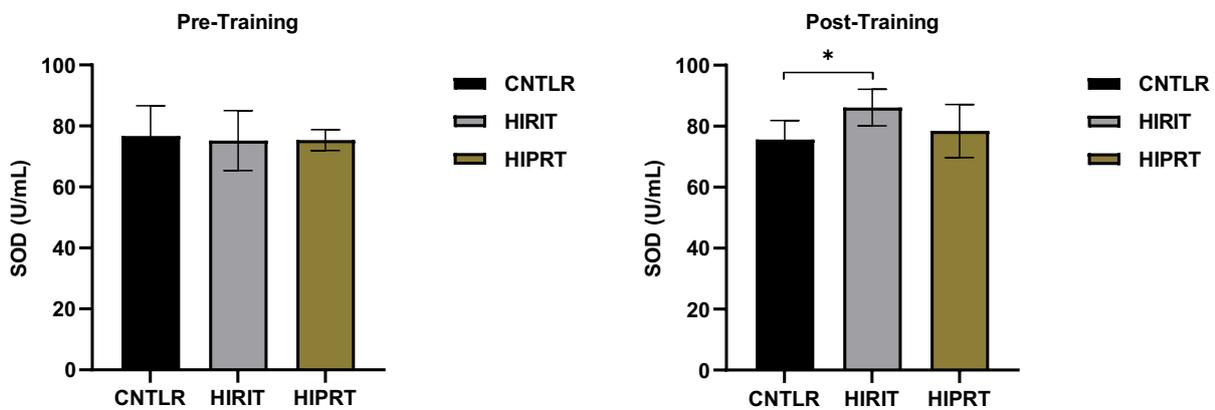


Figure 4. Differences in average SOD levels (U/mL) between groups. Note. (*) Indicates a significant difference from the control group (CNTLR) ($p \leq 0.05$).

Reactive Oxygen Species (ROS). This rise in ROS stimulates the production of antioxidant enzymes, such as SOD, to neutralize free radicals [16]. This mechanism explains why aerobic exercise can more effectively and rapidly reduce oxidative stress.

On the other hand, HIIT strength training tends to increase MDA levels. This marker of lipid peroxidation reflects mechanical muscle damage. Research by Damas et al. [31] showed that resistance training, particularly during the early adaptation phase, causes significant muscle damage. This damage triggers the release of Reactive Oxygen Species (ROS) in the affected tissues. Our findings are consistent with this, as HIIT strength training led to a greater increase in MDA, especially during the early phase of training. Although some studies suggest that resistance training can enhance antioxidant capacity over the long term [30, 31, 32, 33, 34], the relatively short duration of our study may not have been sufficient to capture this adaptation in HIIT strength training.

These results highlight the distinct physiological mechanisms by which the two types of exercise manage oxidative stress. HIIT running increases oxygen consumption, leading to elevated ROS production in the mitochondria [35]. This rise in ROS stimulates the expression of antioxidant enzymes

via the Nrf2 pathway. Nrf2 binds to the Antioxidant Response Element (ARE) on the promoter regions of antioxidant genes, including SOD [36]. Increased SOD activity neutralizes superoxide radicals, which could otherwise cause cellular damage. Furthermore, HIIT running activates the PGC-1 α pathway. This activation supports mitochondrial biogenesis and enhances cellular respiration efficiency, ultimately reducing overall ROS production [37, 38].

In contrast, HIIT strength training induces higher oxidative stress due to mechanical muscle damage [39, 40]. The intense eccentric contractions during resistance training led to localized ROS production from enzymes such as NADPH oxidase and xanthine oxidase. This exacerbates oxidative damage in the affected tissues [39, 41]. Additionally, the release of pro-inflammatory cytokines like TNF- α and IL-6 prolongs oxidative stress. These cytokines activate the NF- κ B inflammatory pathway [42], further contributing to the increase in MDA levels [43]. Although SOD activity increases in response to HIIT strength training, this response is often delayed. The body prioritizes repairing muscle damage before fully engaging its antioxidant defenses [30, 31, 44].

The practical implications of these findings suggest that HIIT running is better suited for individuals aiming to quickly reduce oxidative

stress and enhance antioxidant capacity in the short term. HIIT running-based exercise programs are particularly recommended for those focused on oxidative stress management, such as endurance athletes or individuals seeking to maintain cardiovascular health. In contrast, HIIT strength training provides significant benefits for increasing strength and promoting muscle hypertrophy. However, it is important to account for the elevated oxidative stress during the early adaptation phase. A cautious approach should be taken, emphasizing optimal muscle recovery strategies to minimize excessive oxidative damage.

Study Limitations

First, the four-week intervention period may not have been sufficient to observe long-term adaptations. This is particularly relevant for HIIT strength training, where increases in antioxidant capacity might require more time to develop. Second, the sample consisted exclusively of healthy adolescent males. As a result, the findings may not be generalizable to other populations, such as females, adults, or individuals with specific health conditions. Finally, external factors such as diet and prior fitness levels were not measured. These variables could have influenced the participants' responses to the exercise interventions.

Directions for Future Research

Further research is needed to evaluate the long-term effects of both types of exercise on antioxidant capacity and oxidative stress. Studies with longer intervention durations could offer deeper insights into how antioxidant adaptations develop in HIIT strength training, particularly after the initial muscle damage adaptation phase. Future research should also include a more diverse population, incorporating females and individuals across a

broader age range. This would help determine whether the observed results are consistent across different demographic groups. Additionally, factors such as diet, exercise intensity, and lifestyle habits should be taken into account. This would provide a more comprehensive understanding of how these variables influence the balance between oxidative stress and antioxidant capacity.

Conclusions

Based on the study results, both high-intensity running interval training and high-intensity progressive resistance training, conducted over four weeks, were effective in reducing oxidative stress and increasing antioxidant activity in healthy adolescent males. However, high-intensity running interval training demonstrated greater effectiveness. It more significantly reduced Malondialdehyde (MDA) levels, a marker of cellular damage caused by lipid peroxidation, and increased Superoxide Dismutase (SOD) levels, a key antioxidant enzyme, compared to high-intensity progressive resistance training. These findings suggest that high-intensity running interval training is better suited for managing oxidative stress in healthy adolescent males, although both training methods offer notable benefits.

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Conflict of interest

The authors declare that we all have no conflicts of interest.

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Investigating the effect of a 12-week game skill-based activity in physical education to enhance movement competence of students: a randomized trial

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Abstract

Background and Study Aim

Improving students' physical competence and engagement relies on effective physical education programs. The use of innovative teaching methods is becoming increasingly prevalent in education. This study aims to investigate the effect of game skill-based activity in physical education to enhance movement competence of students.

Material and Methods

The study included 60 students, aged 18 to 21, from different universities. They were divided into experimental and control groups using a quasi-experimental design. The Movement Competency Screen (MCS) was used for assessment. The movement competency test evaluated students' movement skills before and after the intervention. The test included bodyweight squats, lunges and twists, push-ups, bend-and-pull exercises, and single-leg squats.

Results

There were no significant differences in motor competence screening scores between the two groups ($p > .05$). However, the experimental group showed significant improvements across all movement competency screen assessments. This finding highlights the effectiveness of game-based learning in enhancing skill acquisition, coordination, and overall physical skills. In contrast, the control group demonstrated only a moderate increase in movement skills. The results suggest that the game-based collaborative learning method positively impacted motor competence. It promoted the regulated, harmonious, and holistic development of students' movement skills.

Conclusions

The study postulates that a 12-week game skill-based activity in physical education promotes physical competency. It also offers social and psychological benefits. This approach presents a promising pedagogical method to enrich physical education experiences. It encourages cooperation, teamwork, and active participation among students, fostering a more supportive and dynamic learning environment.

Keywords:

movement competence, game-based learning, skill performance, physical education

Introduction

Recently, movement skills in physical education have gained increasing importance as schools emphasize overall student development. The effectiveness of innovative pedagogical approaches in physical education classes significantly influences student engagement and academic performance [1, 2, 3]. Movement skills serve as a fundamental basis

for physical fitness. They also foster cognitive, social, and emotional growth, which are essential for maintaining well-being [4, 5].

However, conventional methods in physical education, often characterized by repetitive drills and teacher-centered sessions, may lead to student disengagement. These methods can also limit opportunities for skill development tailored to diverse learning needs [6, 7]. Numerous studies highlight the significance of collaborative game-based learning for enhancing movement skills and creating a supportive educational environment

[8, 9, 10]. Yet, gaps remain in understanding the comprehensive efficacy of these methods across diverse movement patterns.

Numerous scholars have found that games effectively engage students in an integrative manner [11, 12]. Implementing games in classroom instruction is essential for achieving significant learning outcomes. In physical education, games provide valuable opportunities for promoting collaboration and social interaction [2, 12]. They are a common tool for teaching technical and tactical skills relevant to sports in physical education programs [13]. Using games as an educational tool allows students to engage with theoretical knowledge in an enjoyable and stimulating way [6, 14]. As a result, educators can enhance student engagement in both practical activities and classroom settings [6, 15]. Many studies have shown that games in physical education can boost enjoyment [16], increase motivation [13], improve decision-making [8], and facilitate skill acquisition [17, 18]. These pedagogical methods highlight the importance of student engagement in the learning process. They emphasize enjoyable approaches, such as collaborative game-based learning, within the context of physical education [19, 20, 21].

A substantial body of research has investigated the impact of collaborative game-based learning on the development of movement skills to enhance fundamental abilities [6, 9]. Studies indicate that collaborative learning environments, supported by individual modelling and feedback, lead to better performance and skill acquisition [9, 10]. One investigation assessed the effectiveness of cooperative and collaborative learning methods in improving sports skills among elementary school students. This quasi-experimental study included 50 students divided into one control group and two experimental groups. According to Dyson et al. [22], cooperative and collaborative teaching strategies significantly improved students' sports skill learning.

Navigating the realms of physical education and sports shows that integrating innovative teaching approaches, such as collaborative game-based learning, meets the needs of the current information-driven sector [19, 23]. At the same time, it addresses the complex challenges presented by various movement studies.

Research on current issues in movement competency screening highlights the urgent need for a standardized methodology. Such a methodology should precisely evaluate baseline skill levels, guide focused interventions, and efficiently monitor individual progress over time [24, 25]. This finding underscores the critical importance of comprehensive assessment methods. These methods enhance movement skill competency and promote sustained participation in physical

education activities.

Movement Competency Screening (MCS) and game-based learning (GBL) are innovative methods for improving movement skills in physical education. This integration supports the individualized assessment and improvement of movement patterns. It also engages students through interactive and cooperative learning. Recent research has shown that this strategy can address gaps in traditional physical education. Conventional methods often fail to meet the diverse learning needs of students [2, 26]. The movement competency screen evaluates core skills. It identifies areas where students may need instruction to prevent injuries and improve their physical abilities [27, 28].

In educational institutions, movement competency screens help instructors assess baseline movement ability. They also enable instructors to adapt interventions to improve skill acquisition. Research shows that movement competency screens enhance students' balance, coordination, power, and movement quality. These benefits are especially evident when the screens are tailored to students' skill levels [27, 29]. Additionally, studies suggest that game-based learning environments improve cooperation, motivation, and social development. This approach makes physical education more enjoyable and inclusive [6, 8]. A study by Fizi et al. [13] and Harvey et al. [2] found that game-based learning activities provide repeated practice of movement skills in gaming situations. This method supports physical education goals by improving skill retention and mastery.

Numerous studies indicate that game-based learning can enhance student engagement and academic performance. This approach fosters an interactive environment that encourages skill development through collaboration and immediate feedback [16, 23]. For example, several studies have found that students who participated in collaborative game-based activities reported higher engagement and motivation. They also showed improvements in movement skill proficiency [3, 12, 13]. This method not only enhances students' motor skills but also addresses the emotional aspects of learning. These aspects include motivation, self-esteem, and enjoyment in physical activity.

Research on current issues in movement competency screening highlights the pressing need for frameworks that provide personalized evaluations and specific interventions. However, despite its potential, movement competency screening is still underutilized in combination with collaborative game-based learning methodologies, especially in physical education settings. Movement competency screening offers significant insights into students' basic movement skills and areas needing improvement. Yet, its application in interactive learning contexts remains limited.

There is a clear need to explore how movement competency screening can be integrated into collaborative game-based learning frameworks. This integration could enhance student movement skill development, promote engagement, and accommodate diverse student needs. Therefore, this study aims to investigate the effect of game skill-based activity in physical education to enhance movement competence of students.

Materials and Methods

Participants

The participants in this study were exclusively college students enrolled in the First Semester of 2024-2025. A total of 60 students, aged 18 to 21 ($M = 18.06$; $SD = 0.78$), were selected from various universities. Random sampling was conducted in PE classes, with 30 students assigned to the experimental group and 30 to the control group. Students with disabilities, immune-compromised conditions, or a history of cardiovascular difficulties were exempted from testing due to their unique health needs. The details of the participant groups are shown in Table 1.

Table 1. Subject Features

Group	Male N	Female N	Total
Experimental	15	15	30
Control	15	15	30

Research Design

Prior to the start of the experiment, the study complied with ethical standards. All participants were informed of the study protocols, and informed consent was obtained from each participant. Each participant completed a brief questionnaire about their personal information and history of sports- or physical activity-related injuries. No participants were disqualified from the study, as none presented issues warranting exclusion based on the questionnaire results. A quasi-experimental design was used, which included pre- and post-tests to evaluate fundamental movement skills. The control group received conventional basic movement instructions. In contrast, the experimental group participated in a 12-week game skill-based activity designed to enhance movement competence. Both groups underwent the same pre- and post-intervention skill assessments. Five movement competency screening assessments were conducted to evaluate fundamental movement skills: (1) bodyweight squat, (2) lunge and twist, (3) push-up, (4) bend and pull, and (5) single-leg squat. These assessments are appropriate for evaluating fundamental movement competencies [27]. Afterward, students from both groups participated

in a 12-week Physical Education curriculum under comparable conditions. These conditions included class duration, facility use, and environmental factors.

Experimental Group Design. The researchers implemented a 12-week game skill-based activity framework for the experimental group. Students engaged in diverse game-based movement tasks that required cooperative effort for successful execution. To promote shared responsibility and support, each task demanded active participation from all group members. Tasks were designed to cover various aspects of movement competency assessment. This approach facilitated comprehensive enhancement of participants' performance skills. Students were instructed to work together to achieve common goals. Positive interdependence was developed through shared rewards for group participation, emphasizing the importance of collaboration. Students were responsible for their individual contributions to the group's success. Regular peer evaluations and performance assessments ensured fair and active involvement. Instructors in the experimental group served as facilitators rather than traditional educators. They provided direction, feedback, and support using collaborative learning methods such as peer teaching, learning circles, and group activities. These methods aimed to increase student engagement. The collaborative game-based learning approach was expected to improve movement performance, essential abilities, and interpersonal skills. It also aimed to enhance students' self-efficacy. Standardized assessments, along with feedback from students and instructors, were used to evaluate these outcomes.

Control Group Design. The control group participated in a standard physical activity regimen. This regimen included fundamental movement patterns, games, tactics, and sport-specific drills commonly used in physical education programs in Higher Education Institutions (HEIs). To ensure comparability, the sessions matched the experimental group in frequency and duration. The sessions were held once a week for a specified duration. The curriculum incorporated textbooks, instructional videos, and written exercise and assignment instructions. Teachers conducted the sessions and guided students through exercises and evaluations. This approach emphasized direct instruction and individual achievement rather than group participation. The program focused on improving skill performance, refining fundamental abilities, and fostering sportsmanship. The activities aimed to enhance overall physical ability and develop sport-specific skills in line with physical education goals. The control group's performance and progress were evaluated using standard measurements and instructor observations. These assessments ensured compliance with the physical activity regimen.

Regular evaluations were conducted to track improvements in physical fitness, skill proficiency, and other relevant outcomes. The effectiveness of the conventional learning method was determined by comparing students' initial movement abilities and fitness levels with those measured post-intervention. This comparison helped identify the effects of the collaborative learning strategy and assess its effectiveness relative to conventional teaching methods.

Assessment of Movement Competency Screen (MCS)

1. *Bodyweight Squat:* Stand with your fingertips positioned at the sides of your head. Descend into a squat as far as is comfortable. Return to the standing position.
2. *Lunge and Twist:* Cross your arms and place your hands on your shoulders, with your elbows directed forward. Step into a forward lunge, then twist your torso toward the front knee. Return to the center and resume the standing position. Alternate legs with each repetition.
3. *Push-up:* Perform a standard push-up, maintaining proper form throughout the movement.
4. *Bend and Pull:* Start with your arms extended overhead. Lean forward, allowing your arms to lower beneath your torso. Pull your hands toward your torso, mimicking the motion of a barbell row. Return to the starting position with your arms extended overhead.
5. *Single-Leg Squat:* Perform a bodyweight squat on one leg, with your fingertips resting on the sides of your head. Extend the non-weight-bearing leg behind your torso. Descend into the squat as far as is comfortable, then return to the standing position.

Statistical Analysis

The data were analyzed using SPSS version 20. Descriptive statistics – including the mean,

frequency, and standard deviation – were used to examine the quantitative data. Pre- and post-test scores within each group were compared using a paired sample t-test. Differences between the experimental and control groups were assessed using an independent sample t-test. The significance threshold was set at $p < 0.05$.

Results

A pre-experimental movement competency test was conducted for both the experimental and control groups. This test established a baseline for evaluating students' movement skill performance and ensured comparable outcomes. The results are presented in Table 2. Table 2 shows the average differences in movement competency screening assessments between the control and experimental groups of college students before the implementation of the collaborative game-based learning method. No significant differences were observed in any of the movement competency screening assessments between the two groups ($p > .05$). This indicates that the movement skill performance of the two groups was similar. Consequently, the 12-week game skill-based activity in the Physical Education course could proceed for each designated group.

Movement assessments were used to compare the experimental and control groups after the experiment in the final phase of the Physical Education course. The same tests from the original assessment were utilized. The outcomes of the independent samples t-test for these comparisons are displayed in Table 3. The results revealed a significant difference in movement competency screening tests between the control and experimental groups after the 12-week game skill-based activity. Following the experiment, the mean scores across all five movement competency tests were significantly higher in the experimental group compared to the control group ($p < .001$). These

Table 2. Pre-test scores for both experimental and control groups

Movement Patterns	Groups	N	M	SD	t-value	p-value
Body Weight Squat	Experimental	30	5.70	1.055	-0.697	0.489
	Control	30	5.87	.776		
Lunge and Twist	Experimental	30	5.57	1.07	-0.217	0.829
	Control	30	5.63	1.30		
Push Up	Experimental	30	4.80	.41	-1.908	0.061
	Control	30	5.10	.76		
Bend and Pull	Experimental	30	5.70	1.02	-1.776	0.081
	Control	30	6.13	.86		
Single Leg Squat	Experimental	30	5.0	.743	-1.795	0.078
	Control	30	5.40	.97		

Table 3. Post-test scores for both experimental and control groups

Movement Patterns	Groups	N	M	SD	t-value	p-value
Body Weight Squat	Experimental	30	9.00	1.76	2.363	.021
	Control	30	8.17	0.79		
Lunge and Twist	Experimental	30	8.63	0.67	3.471	<.001
	Control	30	7.87	1.01		
Push Up	Experimental	30	13.50	1.53	5.643	<.001
	Control	30	11.47	1.25		
Bend and Pull	Experimental	30	8.30	1.37	3.385	<.001
	Control	30	7.40	0.50		
Single Leg Squat	Experimental	30	11.13	1.01	4.595	<.001
	Control	30	9.93	1.02		

Table 4. Paired sample t-test of scores in the experimental and control groups on movement competency test

Variable	Group	Pre-Test	Post-Test	t-value	p-value
		M ± SD	M ± SD		
Body Weight Squat	Experimental	5.70 ± 1.06	11.14 ± 1.01	-19.242	< .001
	Control	5.87 ± 0.78	9.93 ± 1.02	15.503	< .001
Lunge and Twist	Experimental	5.57 ± 1.07	13.50 ± 1.53	-24.68	< .001
	Control	5.63 ± 1.30	11.47 ± 1.25	16.858	< .001
Push Up	Experimental	4.80 ± 0.41	9.0 ± 1.76	-12.101	< .001
	Control	5.10 ± 0.76	8.17 ± 0.79	16.024	< .001
Bend and Pull	Experimental	5.70 ± 1.02	8.63 ± 0.669	-13.372	< .001
	Control	6.13 ± 0.86	7.47 ± 1.01	6.966	< .001
Single Leg Squat	Experimental	5.0 ± 0.74	8.30 ± 1.37	-14.006	< .001
	Control	5.40 ± 0.97	7.40 ± 0.50	10.117	< .001

findings demonstrate that the collaborative game-based learning technique positively influenced movement competency. It fostered regulated, harmonious, and holistic growth in students' movement skill performance.

Movement assessments were used to compare the experimental and control groups after the experiment in the final phase of the Physical Education course. The same tests from the original assessment were utilized. The outcomes of the independent samples t-test for these comparisons are displayed in Table 3. The results revealed a significant difference in movement competency screening tests between the control and experimental groups after the 12-week game skill-based activity. Following the experiment, the mean scores across all five movement competency tests were significantly higher in the experimental group compared to the control group ($p < .001$). These findings demonstrate that the collaborative game-based learning technique positively influenced

movement competency. It fostered regulated, harmonious, and holistic growth in students' movement skill performance.

Discussion

This study aimed to evaluate the efficacy of a 12-week game-based learning program in improving skill performance among students in physical education classes. The findings support previous research that highlights the benefits of collaborative learning for enhancing skill performance and fostering strong connections among students [9, 10]. Furthermore, earlier studies have demonstrated that collaborative game-based learning effectively enhances skill development and social competencies in educational settings [6, 15].

The study results show a statistically significant improvement in all movement competency tests for the experimental group. This demonstrates the effectiveness of the 12-week game skill-based activity in the Physical Education course

for enhancing students' movement skills. These findings align with prior research that highlights how game skill-based activities foster an engaging learning environment. In such environments, students actively participate and support each other, leading to improved physical abilities and outcomes [12, 15]. These pedagogical approaches promote greater student engagement in physical activity tasks. As a result, they improve movement abilities, balance, and coordination [15, 30, 31].

Furthermore, numerous studies have demonstrated that game skill-based activities in Physical Education can significantly enhance physical skills. These skills include power, stamina, and endurance. This is achieved by incorporating movement patterns that promote individual skill development and collaborative problem-solving [26, 29]. Game skill-based activities engage students in attaining physical goals. They also promote peer learning, where students observe and emulate effective strategies from their peers. This results in an overall improvement of physical competencies. Thus, game-based learning has been linked to increased motivation and performance in Physical Education environments [9, 23]. Collaborative environments often boost intrinsic motivation by fostering a sense of belonging and purpose. This occurs because each individual contributes to the group's success [23]. Increased motivation is important because it encourages students to overcome physical challenges, set personal performance goals, and consistently participate in physical activities. Research shows that this collaborative approach not only enhances motivation but also fosters self-efficacy [32]. As a result, students develop confidence in their physical abilities, which further improves skill performance [17, 33].

Similar research in physical education found that incorporating collaborative game-based learning techniques into sports and physical activity instruction increases engagement, success, and skill acquisition [8, 9, 10]. This suggests that students not only improve sport-specific skills but also develop stronger social relationships and teamwork abilities. Furthermore, research has highlighted the positive effects of game skill-based activities on student engagement in physical education settings [9]. These findings emphasize that using game-based learning methods in PE classes significantly boosts students' motivation. This increased motivation is essential for sustaining long-term engagement. A study conducted by Casey and Quennerstedt [10] investigated the use of skill-based learning techniques in teaching physical education and sports skills. Their findings show that these techniques substantially enhance student engagement and skill acquisition. Both of these factors are necessary for effective learning outcomes in physical education.

These studies provide a fundamental understanding of the benefits of skill-based learning, particularly in improving movement competence in physical education programs. Although recent findings support this approach [16, 19, 26], some critics argue that tactical games may limit its applicability. They suggest that this method is less suitable for aspects of physical education involving less structured or more customized physical activities and sports.

In addition, prior research has shown that a collaborative game-based learning strategy enhances not only physical capabilities but also psychological factors. These factors include motivation, confidence, optimism, and self-efficacy [23, 32, 33]. This suggests that collaborative game-based learning has a substantial effect that goes beyond improving physical skills. It also promotes emotional and social growth. These comprehensive findings allow researchers to propose further investigations into the adaptation and modification of collaborative game-based learning strategies. This could help enhance various physical education environments and support all dimensions of student learning and skill development. This comprehensive approach situates the study within the broader framework of prior research [9, 10, 20]. It provides a more thorough analysis and highlights the diverse benefits of collaborative game-based learning in physical education.

This body of knowledge is enriched by research that examines the implementation of collaborative game-based learning within physical education. The current study not only supports previous findings but also expands upon them. It demonstrates that collaborative game-based learning can lead to measurable improvements in fundamental movement skills.

The findings suggest that this approach fosters a comprehensive physical education experience. It emphasizes teamwork, mutual support, and personal development. These elements are crucial for sustaining lifelong engagement in physical activity and sports. Future studies could explore these dimensions further by analyzing the effects of different collaborative tasks on specific physical skills. Additionally, researchers may investigate how these improvements correlate with real-world physical performance and health outcomes.

Limitations of the Study

Although the current research offers novel insights into how collaborative game-based learning improves students' movement skill performance, it is important to acknowledge its limitations. First, the sample was limited to first-year college students participating in PATHFIT 1 at MSU-Iligan Institute of Technology. This restricts the relevance of the findings to other age demographics, educational levels, or students from different institutions.

The limited demographic breadth may affect the generalizability of the results to larger populations. Moreover, the study excluded individuals with disabilities, immunocompromised conditions, or a history of cardiovascular issues, focusing solely on healthy participants. Although this approach ensured participant safety, it implies that the findings may not be entirely applicable to students with diverse health needs. Finally, while the collaborative game-based learning approach yielded positive outcomes, its specific framework and tasks may limit its applicability to other forms of physical education that do not incorporate tactical or game-based learning.

To address these limitations, future studies could expand the participant demographic to include students of different ages, educational backgrounds, and health conditions. This would provide insights into how collaborative game-based learning affects diverse physical education groups. To determine long-term advantages, future research could investigate the effects of collaborative learning on movement proficiency, physical fitness, and psychological factors such as motivation and self-efficacy. Additionally, applying collaborative learning to physical activities beyond tactical or game-based tasks may reveal its benefits for a broader range of skills and competencies. Finally, collecting qualitative data through interviews or surveys with participants and instructors may shed light on subjective collaborative learning experiences and contextualize quantitative findings. These improvements would deepen our understanding of

collaborative game-based learning and its potential to enhance movement skill performance in physical education settings.

Conclusions

This study highlights the potential of a 12-week game skill-based activity in physical education to enhance movement competence among students. The collaborative game-based learning approach facilitates skill acquisition while fostering teamwork, motivation, and engagement - elements vital for comprehensive development in physical education. To effectively meet the diverse needs of students and improve skill development, educators should employ a variety of instructional approaches. Collaborative game-based learning is particularly recommended for promoting physical skills and social competence. Broader implementation of this method in different study groups and sports training programs may yield beneficial outcomes. Furthermore, educators should be informed about the advantages of integrating multiple pedagogical strategies to create tailored instruction. This will help establish a holistic and effective learning environment that accommodates students' varied interests and proficiency levels.

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