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ORIGINAL ARTICLE

Increase the speed of running 100 meters using the bench and skipping training methods

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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 Running 100 meters requires optimal speed, strength, and physical endurance. Running speed is often a key indicator of physical ability and athletic performance. However, not everyone achieves optimal speed and physical ability in running the 100 meters. Many factors influence a student's running performance, including the training methods used. The aim of the research is to determine the increase in speed for running 100 meters using bench and skipping training methods.

Material and Methods This research is an experimental study aiming to find cause and effect relationships in one or more experimental groups through different training treatments. The design used is a two-group pretest-posttest design. The participants were male students actively involved in sports activities, capable of performing running techniques well, and willing to participate in the training sessions. Initially, students underwent a pretest to determine their treatment group by ranking the pretest scores. This allowed the formation of two groups: one group of 15 students participating in bench climbing exercises, and another group of 15 students engaging in skipping exercises, using ordinal pairing. The instrument used for the 100-meter running test is the 100-meter running test.

Results Based on the results of hypothesis testing using pretest and posttest t-tests, the 100-meter running speed after bench up and down training was 4.621. The pretest and posttest data for 100-meter running speed with skipping training was 4.790. For the posttest, the running speed for 100 meters with bench up and down training and skipping training was 4.240. The two-way p-value was 0.000, which is less than 0.05, indicating a significant difference in the 100-meter running speed before and after the exercise.

Conclusions Bench climbing exercises can increase the strength of the primary leg muscles used in sprinting, such as the quadriceps, hamstrings, and calves. These exercises improve body balance and coordination, which are crucial for efficient running posture and technique. Meanwhile, skipping can enhance explosive power and the ability of leg muscles to generate power quickly and efficiently. Skipping also improves coordination between hands and feet, aiding in maintaining rhythm and efficiency in running movements. Overall, bench climbing exercises are more effective in improving 100-meter running performance compared to skipping exercises.

Keywords: running, 100 meters, training, going up, down, bench, skipping

Introduction

Achieving optimal performance in the 100-meter dash remains a significant challenge for many athletes. Despite rigorous training, some struggle to reach their maximum potential due to a variety of factors. Identifying the most effective training methods to overcome these challenges is essential. The 100-meter running speed is one of the most critical performance measures in athletics and is often the main indicator of an athlete's ability in competition [1]. Increasing running speed over this distance requires not only high muscle strength and explosive power but also optimal coordination, agility, and physical endurance. Therefore, choosing the right training method is crucial for achieving the best performance [2, 3]. Plyometric training is widely recognized as an effective method for increasing explosive ability and speed [4]. Two common forms of plyometric training are bench up and down exercises and skipping exercises. Bench up and down exercises focus on strengthening leg muscles and developing explosive power, while skipping exercises improve coordination, agility, and overall muscle strength [5]. Both methods have significant potential in enhancing 100-meter running performance, but their comparative effectiveness in short-distance running still needs further exploration [6].

The up and down bench exercise effectively strengthens the leg muscles, including the thighs and calves. This strength is crucial for increasing thrust during running, thereby enhancing maximal speed [7, 8]. By increasing leg muscle strength through up and down bench training, the body's ability to produce greater power in a short time improves,

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which is essential for the 100-meter sprint [9]. This exercise develops explosive movement speed, vital for reaching maximum speed quickly after the start [10]. Additionally, bench climbing exercises enhance body coordination and overall stability, leading to increased movement efficiency while running [11].

Skipping exercises involve complex coordinated movements between the legs and arms, which help improve motor skills and body balance. This is essential for increasing movement efficiency while running [12]. Skipping exercises strengthen the leg muscles, particularly the calves and thighs, and enhance body stability. This contributes to stronger thrust during fast running [13, 14]. Skipping increases stride frequency, a key factor in boosting sprint speed. This exercise also develops the spring or propulsive strength of the legs, necessary for reaching maximum speed quickly. Incorporating skipping into a regular interval training program can improve aerobic and anaerobic capacity, which is crucial for endurance and quick recovery between sprints.

Previous research has shown that strengthening muscles through plyometric training can improve leg propulsion and movement efficiency, which are essential for sprinting. However, there are differences in how these two methods influence the physical components that support running speed [15]. Up and down bench training, focusing on strength and explosive power, is more effective in increasing initial acceleration [16]. Meanwhile, skipping exercises, which improve agility and coordination, contribute to maximum speed and stride efficiency [17]. Previous studies often focus on one type of plyometric training, such as only bench climbing or only skipping. This study combines these two methods and evaluates their synergistic effect on 100-meter running speed. This approach seeks to understand how combining these exercises can produce more significant performance improvements than using either method alone.

Focus on developing leg strength and body propulsion by performing up and down bench movements, which require strength and coordination. This method places more emphasis on developing coordination, movement speed, and the ability to increase stride frequency [18, 19]. The study analyzed the differences in leg strength gains between these two methods by measuring calf and thigh muscle strength before and after exercise. Evaluation of improvements in 100-meter sprint speed, along with contributing factors such as stride frequency and reaction time, was part of the analysis [20, 21]. Sprint time was measured using a stopwatch, and biomechanical measurements were used to analyze running technique [23]. The focus was on measuring the development of leg muscle strength and its influence on running speed [24]. Additionally, the evaluation included participants' ability to improve body coordination and stability during training and its impact on running performance [24, 25].

Some problems experienced by athletes when performing up and down bench exercises include the intensive use of leg muscles, which can increase the risk of injury to joints such as the knees and ankles. This risk is especially high if the athlete does not warm up sufficiently or does not pay attention to correct technique [27]. The same applies to skipping exercises, where poor coordination or excessive repetition can lead to foot or ankle injuries. Proper technique is essential for both exercises to prevent injury and maximize their benefits [28]. Athletes who are not adequately trained in the techniques of bench climbing or skipping will not achieve optimal results and may risk injury. Consistency in training is crucial for increasing 100-meter running speed. However, athletes often struggle to maintain consistency due to various reasons such as busy schedules, fatigue, or lack of motivation towards monotonous training.

The analysis of existing research indicates that most of the studies reviewed were primarily focused on professional athletes. Regarding the level of collegiate sports, the recommendations reviewed are not always adaptable. Therefore, there is a need to seek alternative solutions. The aim of the research is to determine the increase in speed for running 100 meters using bench and skipping training methods.

Materials and Methods

Participants

This test was carried out by male students who were actively involved in sports activities, able to perform running techniques well, and willing to participate in the training. A total of 30 students participated. Initially, students underwent a pretest to determine the treatment groups. Based on the pretest scores, the students were ranked and then divided into two groups using ordinal pairing: 15 students participated in the bench climbing exercise (Group A), and 15 students in the skipping exercise (Group B).

Research Design

This research is a type of experimental study aiming to find cause-and-effect relationships in one or more experimental groups through different training treatments. The design used is a two-group pretest-posttest design [29], where a pretest is conducted before the treatment and a posttest after the treatment. The research design is illustrated in Figure 1.

The pretest and posttest involved a 100-meter running test. Group A performed the up-and-down bench exercise, and Group B performed skipping exercises. Each group followed a training program consisting of 18 sessions over 6 weeks. For maximum performance, participants in Group A performed the bench exercise 54 times per session, while those in Group B did the skipping exercise 56 times per session. The intensity levels were moderate (70%), heavy (80%), and light (60%).

The 100-meter running test involved students starting behind the starting line and performing a squat start. Upon the ready signal, students ran as fast as possible to the finish line [30].

Statistical Analysis

Data analysis included prerequisite tests, starting with the normality test using the Kolmogorov-Smirnov test. If the significance level is above 0.05, the data can be considered normally distributed. A homogeneity test was then performed to determine the distribution of values to be analyzed, using the F-test on the pretest and posttest data. To test the hypothesis, a t-test was used to compare the averages of Group A and Group B, with the analysis conducted using SPSS 26.

Results

The research findings were obtained based on inferential descriptive statistical analysis, explaining the results of the pretest and posttest implementation at 100-meter running speed. The results include the average score, median, mode, standard deviation, variance, frequency distribution, percentage, and histogram. The descriptive statistics for the 100-meter running speed test during the pretest and posttest are presented in Table 1.

Based on Table 1, differences are observed in the descriptive statistical tests. Specifically, the average pretest 100-meter running speed was 15.00 seconds, while the posttest speed was 14.70 seconds using the bench up and down exercise. In contrast, the pretest 100-meter running speed with skipping training averaged 15.00 seconds, and the posttest averaged 13.08 seconds. These results suggest that the bench up and down exercise led to a better improvement in 100-meter running speed compared to the skipping exercise. The results of the data normality test are shown in Table 2.

The data normality test, using the Kolmogorov-Smirnov test, indicated that each variable had a significance value greater than $\alpha = 0.05$, suggesting a normal distribution. The variance homogeneity test results are presented in Table 3.

The homogeneity of variance test showed that each variable had a significance value greater than $\alpha = 0.05$, indicating that the data is homogeneous. The hypothesis testing results are shown in Table 4.

Based on the hypothesis testing using pretest and posttest t-tests, the 100-meter running speed using bench up and down training showed a t-value of 4.621. The pretest and posttest data for the 100-meter running speed with skipping training showed a t-value of 4.790. Meanwhile, the posttest for running 100 meters using both bench up and down and skipping exercises resulted in a t-value of 4.240, with a significance value (p-value) of 0.000 < 0.05. This indicates a significant difference in the 100-meter running speed before and after the exercises. The histogram of the average differences in 100-meter running speed is presented in Figure 2.

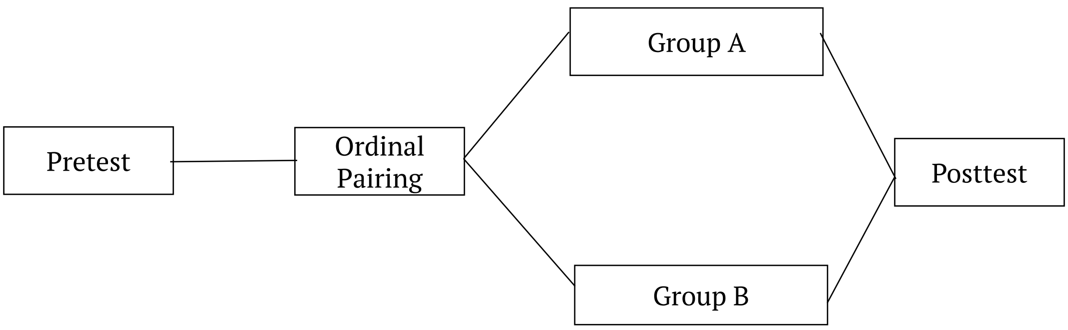

Figure 1. Two groups pretest posttest research design

Table 1. Descriptive statistical test of the pretest and posttest for 100 meter running with bench and skipping exercises

Data	N	Mean	Median	Mode	Standard Deviation	Variance	Minimum	Maximum
Pretest (bench up and down)	15	15.09	14.90	13.10	1.52	2.33	13.10	17.81
Posttest (bench up and down)	15	13.08	12.80	12.50	0.68	0.47	12.17	14.22
Pretest (skipping)	15	15.11	14.90	13.00	1.52	2.30	13.06	17.78
Posttest (skipping)	15	14.70	14.51	13.01	1.31	1.71	13.01	17.40

Note: N - Number of participants

Table 2. Results of the data normality test

Variable	df	Statistical
Pretest score (bench up and down)	15	0.128
Posttest score (bench up and down)	15	0.168
Pretest score (skipping)	15	0.102
Posttest score (skipping)	15	0.156

Note: df - Degrees of freedom

Table 3. Results of the data homogeneity test

Variable	Statistical	Significance
Pretest and posttest data for running 100 meters (bench)	6.773	0.105
Pretest and posttest data for running 100 meters (skipping)	0.654	0.425
Posttest data for 100 meters running (bench and skipping)	2.836	0.103

Note: Significance level (α) - 0.05

Table 4. Test results before and after the bench up and down exercise and skipping exercise on 100 meter running speed

Variable	F	Sig.	t	P-Value
Pretest and posttest data on 100 meter running speed (bench)	6.773	0.105	4.621	0.000
Pretest and posttest data on 100 meter running speed (skipping)	0.654	0.425	4.790	0.000
Posttest data on 100 meter running speed (bench and skipping)	2.836	0.103	4.240	0.000

Note: Sig. - Significance; P-Value - Probability value

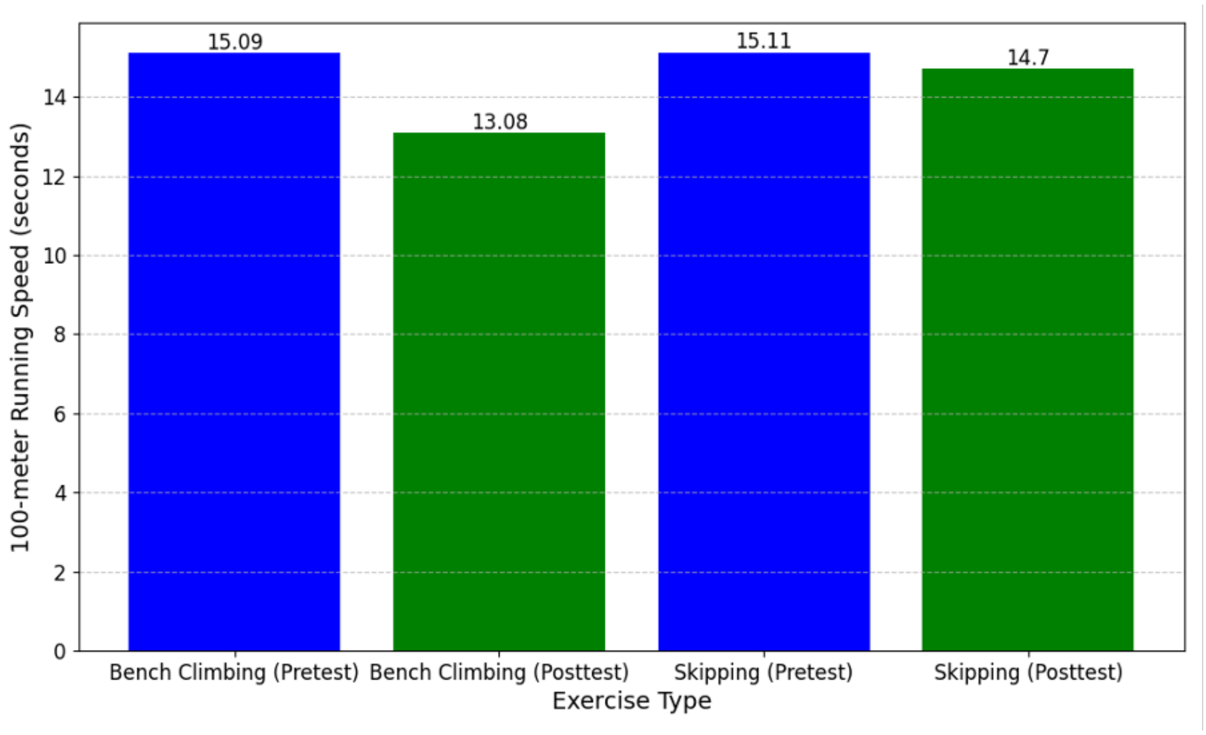

Figure 2. Histogram comparing 100-meter running speed before and after training with bench climbing and skipping exercises

Discussion

This research was conducted to explore the effectiveness of two training methods, namely bench climbing and skipping exercises, in increasing 100-meter running speed. Up and down bench training has been proven to increase leg muscle strength more significantly than skipping training. This is due to the more intense movement against gravity in the up and down bench exercise. Both training methods showed an increase in 100-meter running speed. However, the group that underwent up and down bench training experienced greater improvements compared to the skipping group.

Skipping exercises provide greater benefits in improving coordination and balance than bench climbing exercises [31]. Skipping involves rhythmic movements that help develop coordination skills [17, 31]. This exercise is also effective in increasing leg muscle strength, an important factor in running speed [33]. Increased leg muscle strength directly correlates with the ability to push the body faster in the 100-meter run. Although skipping is not as effective as bench climbing in terms of increasing muscle strength, it still makes a positive contribution in terms of balance and coordination. These skills are crucial for optimizing running technique and minimizing the risk of injury.

Based on the findings, combining both training methods may be the optimal approach. Up and down bench exercises can focus on developing muscle strength, while skipping exercises can complement by improving coordination and balance. This research shows that a structured and focused training approach can significantly improve athletes' running performance. Coaches can consider integrating these two methods in their training programs to maximize performance improvements in 100-meter sprint athletes.

Up and down bench training significantly increases leg muscle strength compared to skipping training. This exercise involves movements against gravity that place additional load on the leg muscles, thereby increasing muscle strength. Previous research by Deng et al. [34] showed that plyometric exercises, such as going up and down a bench, effectively increased leg muscle strength and endurance. These findings are consistent with our results, indicating that bench up and down exercises provide greater strength gains compared to skipping exercises, which focus more on improving coordination and balance.

Both training methods (up and down the bench and skipping) showed an increase in 100-meter running speed. However, the group that did the up and down bench exercise experienced more significant improvements. This suggests that increased muscle strength through bench up and down training has a direct impact on sprint performance. The study by Jiang et al. [35] stated that increases in muscle strength are directly correlated with sprint speed. These findings support our research results, showing that bench up and down training, which increases muscle strength, also enhances running speed more effectively compared to skipping.

Skipping exercises provide greater benefits in terms of improving coordination and balance compared to getting up and down on a bench. Skipping involves complex rhythmic movements, helping in the development of coordination and balance skills, which are also important for running performance. According to research by Ma et al. [36], exercises involving rhythmic movements, such as skipping, are effective in improving coordination and balance. The results of this study are consistent with our findings, indicating that skipping can be a useful addition to a running training program to improve aspects of coordination and balance.

Combining up and down bench and skipping exercises can provide optimal results. Up and down bench training focuses on increasing muscle strength, while skipping strengthens coordination and balance. This combination can produce more comprehensive performance improvements in the 100-meter dash. The study by Nash et al. [37] showed that a balanced training program, which includes different types of exercise, provides better results in athletic performance. The results of our study support this approach, showing that the combination of different training methods can optimize training results.

This research confirms the importance of variety in athletic training programs. Up and down bench training provides a significant increase in muscle strength, which is important for running speed. Skipping, on the other hand, improves coordination and balance. The combination of these two methods shows optimal results, supporting existing literature regarding the effectiveness of balanced and structured exercise programs. This research makes an important contribution to understanding how different types of training can be combined to improve overall running performance.

The limitation of this research is that it uses a limited sample size, so the results cannot be widely generalized. Additionally, the duration of the training used in this study was relatively short, with only 18 sessions, which may not be sufficient to observe the long-term effects of the up and down bench and skipping training methods on running speed. The research was conducted in environmental conditions that differ from real competition settings, such as weather variations or different field conditions. Individual differences in basic physical abilities, motivation, and health conditions can influence results, making it difficult to ensure that the results obtained are purely due to the training method applied.

In conclusion, this study demonstrates that combining up and down bench exercises with skipping exercises can significantly enhance 100-meter running speed by improving both muscle strength and coordination. These findings support the implementation of varied training methods to optimize athletic performance. Future research should focus on involving larger and more diverse samples to enhance the generalizability of the results. Additionally, extending the duration of the training programs will help observe long-term effects on running performance. Comparing the effectiveness of bench climbing and skipping exercises with other established training methods can provide a broader understanding of their relative advantages. Finally, conducting studies in conditions that closely mimic real competition environments will yield more applicable results for athletes.

Conclusions

Getting up and down the bench can increase the strength of the main leg muscles used in sprinting, such as the quadriceps, hamstrings, and calves. It also improves body balance and coordination, which are important for efficient running posture and technique. Meanwhile, skipping can increase explosive power and the ability of leg muscles to produce power quickly and efficiently. It improves coordination between hands and feet, helping to maintain the rhythm and efficiency of running movements. Up and down bench training is more effective in improving the 100-meter run compared to skipping training. The implications of such training include improved strength, explosive power, coordination, and cardiovascular condition, allowing athletes to achieve and maintain high speeds during the 100-meter run more effectively. Additionally, exercises that strengthen muscles and improve balance help prevent common injuries in sprinters, such as hamstring strains or injuries to the knee and ankle joints.

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ORIGINAL ARTICLE

Exploring the physical activity levels of Egyptian women with premenstrual syndrome: a preliminary study

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Abstract

Background and Study Aim Premenstrual syndrome (PMS) affects a significant proportion of women, impacting their daily lives and well-being. The association between physical activity levels, the prevalence of premenstrual syndrome (PMS), and the severity of PMS remains debatable. Therefore, this study aimed to identify physical activity levels among a cohort of Egyptian females with PMS.

Material and Methods This study included one hundred females with PMS. Physical activity levels, anaerobic power, aerobic capacity, BMI, and dysmenorrhea were investigated. PMS severity was assessed using the Premenstrual Syndrome Scale (PMSS), and the females' physical activity was evaluated using the International Physical Activity Questionnaire (IPAQ). The 1-mile submaximal test and the Running-Based Anaerobic Sprint Test (RAST) were used to assess aerobic capacity and anaerobic power, respectively.

Results The findings revealed a significant association between PMS severity and physical activity ($p < 0.05$). There was no significant difference in aerobic capacity among those with mild, moderate, and severe PMS ($p > 0.05$). There was no significant association between PMS severity and marital status ($p > 0.05$), whereas there was a significant association with dysmenorrhea ($p < 0.05$), especially among moderate and severe PMS sufferers. Females with severe PMS had a significantly higher BMI than those with mild PMS ($p < 0.05$) and those with moderate PMS ($p < 0.05$). Mild and moderate PMS females showed no significant difference in BMI ($p > 0.05$).

Conclusions It can be concluded that physical activity levels and BMI may affect PMS. Therefore, being physically active and maintaining a normal-range BMI might reduce PMS severity.

Keywords: aerobic capacity, anaerobic power, physical activity, premenstrual syndrome.

ABBREVIATIONS
PMS: Premenstrual syndrome
PMSS: Premenstrual Syndrome Scale
BMI: Body Mass Index
IPAQ: International Physical Activity Questionnaire
RAST: Running-Based Anaerobic Sprint Test

Introduction

Premenstrual syndrome (PMS) is a widespread condition that significantly affects the quality of life of many women worldwide. To better understand PMS in the context of Egyptian women, additional research is essential. This effort can contribute to more effective management strategies and support systems for those affected [1].

PMS is a recurrent pattern of symptoms occurring during the luteal phase of the menstrual cycle, with a global prevalence of 48% [1]. It is characterized by significant psychological and somatic manifestations that greatly impact women's daily lives, including work and everyday activities, resulting in considerable distress and impairment in functional ability [2]. Furthermore, PMS is more likely to affect sexual life, leading to higher levels of sexual distress and relationship problems. It also contributes to psychological issues, such as an increased risk of suicide in hormone-sensitive females [3, 4]. The cause of PMS remains uncertain; however, hormone imbalance, thyroid disorders, fluid retention, hypoglycemia, genetics, stress, and psychological factors are recognized as risk factors for PMS [5].

Physical activity is observed to reduce the severity of PMS by increasing endorphin levels, improving mood and psychological well-being, reducing steroid hormones, and enhancing oxygen transport to muscles [6]. However, there is a debate in the literature regarding this observation, as some researchers reported a relieving effect of exercise on

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PMS [6, 7], while others found no association [8,9], and some indicated that females who exercised more had increased severity of PMS compared to those who exercised less. This conflict can be interpreted by the belief and awareness of women with severe PMS that exercise may attenuate their symptoms, prompting them to initiate exercise for that reason. Additionally, high-intensity activities have been proven to be related to increased stress, fatigue, and menstrual abnormalities, which may aggravate PMS symptoms [10, 11]. Thus, it remains difficult to determine whether exercise is a cause of or response to their symptoms. Because of these contradictory results, further studies are needed, considering the confounding factors regarding the BMI of affected women, dysmenorrhea, and the type and extent of physical activity, which were not previously tracked among the Egyptian population. We hypothesized a relationship between physical activity and PMS severity.

A prior study has shown that menstrual irregularities, such as intermenstrual bleeding, frequent menstruation, menorrhagia, prolonged menstruation, hypomenorrhea, and irregular menstruation, negatively affect anaerobic performance by impacting the extensibility of ligaments and tendons [10]. However, studies on the correlation between PMS and anaerobic power are scarce. Therefore, a conclusive assumption concerning the relationship between anaerobic power, aerobic fitness, and PMS symptoms requires more thorough investigation [12]. To our knowledge, no study has tracked this association among the Egyptian population. Thus, this study aimed to investigate the association between physical activity levels and the severity of PMS among a cohort of Egyptian females.

Materials and Methods

Participants

This study was designed as a cross-sectional study. One hundred females suffering from PMS participated. They were aged between 20 and 35, with a mean age of 27.1 ± 4.98 years. Their menstrual cycle had a mean duration of 27.5 ± 2.52 days. Participants were excluded if they were taking oral contraceptives or hormonal therapy, smoking, or suffering from chronic disorders such as diabetes, renal or thyroid dysfunction, or psychiatric or gynecological diseases (including a history of polycystic ovarian syndrome).

Before commencing the research, the Ethical Committee of the Faculty of Physical Therapy at Cairo University granted ethical approval (No.: 012/003220).

Before taking part in the study, all participants were given an informed consent form to sign after receiving a thorough explanation of the study protocol.

Sample size determination

The sample size was calculated using G*POWER statistical software (version 3.1.9.2; Universitat Kiel, Franz Faul, Germany), assuming a modest association between physical activity level and PMS, resulting in a minimum sample size of N=84. The number was increased to 100 to account for potential dropouts. The calculation used α=0.05, β=0.2, and a moderate effect size of 0.3.

Procedure

Females were recruited from social media platforms. Once a female contacted the study coordinator (the third author), an interview was scheduled with a gynecologist to assess her eligibility specific to PMS. The average menstrual cycle length was computed to estimate the late luteal phase, after asking all participants to keep a calendar record of their menstrual cycle for the previous three months [13]. Aerobic power, anaerobic power, and fatigue index were assessed during the late luteal phase. Before starting the study, participants were given a detailed description of the study. They were required to sign a letter of consent before the interview.

According to Figure 1, one hundred and eighteen females were recruited. Eighteen were excluded: nine were diagnosed with polycystic ovarian syndrome, six were taking oral contraceptive drugs, two did not complete the evaluative procedures, and one refused to participate. Thus, one hundred females participated (Fig. 1). To be diagnosed with PMS, participants were instructed to complete the questionnaire at the first appointment with the gynecologist. They were asked to fill out a data collection sheet with their age, menarche age, menstrual cycle frequency, duration, dysmenorrhea, marital status, and employment status. Weight and height were measured to calculate BMI. After confirming their eligibility to join the study, a second appointment was scheduled 2-3 days before the expected date of menstruation in the morning to assess aerobic power, anaerobic power, and fatigue index, and to complete the IPAQ.

Outcome measures

Assessment of premenstrual syndrome

We used the PMSS, which consists of forty questions, including three subscales (physiological, psychological, and behavioral symptoms). It is a 5-point Likert-type scale: never scored as 1, rarely as 2, sometimes as 3, very often as 4, and always as 5 points. The total score obtained from the subscales establishes the PMSS total score, which ranges from 40 as the minimum to 200 as the highest score. PMS symptoms are graded into four classifications as follows: no symptoms (1–40), mild (41–80), moderate (81–120), severe (121–160), and very severe (161–200). A total score of 80 or higher indicates the presence of PMS. The scale's inter-rater reliability (Cronbach's Alpha) is 0.97 [14].

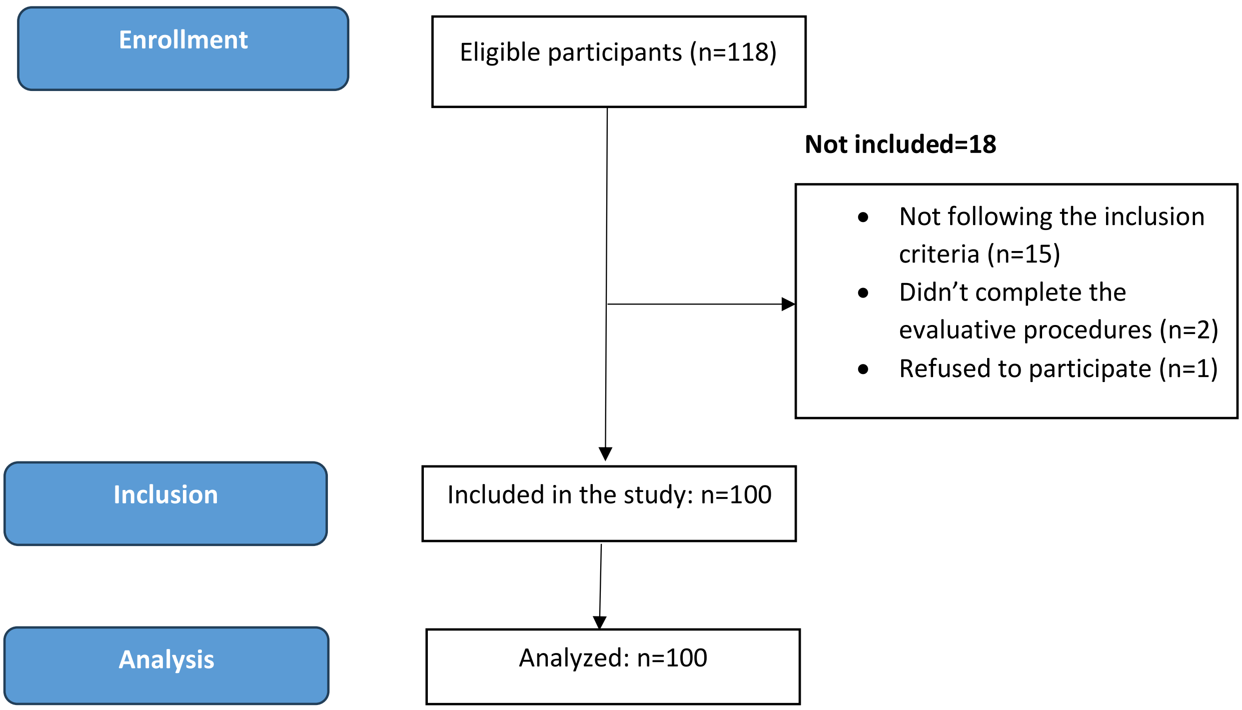

Figure 1. Flow diagram of the study

Assessment of physical activity

Physical activity level was evaluated using the International Physical Activity Questionnaire (IPAQ) [15]. The IPAQ is a self-administered assessment tool comprising 27 items to evaluate physical activity levels among adults aged 15 to 69. Participants were asked to recall the types of physical exercises they performed, how often (days per week), and for how long (hours and minutes per day) they engaged in these activities over the past week. The evaluation is based on the intensity of the activities, categorized as vigorous (such as aerobic walking, running, and jogging), moderate (such as general home exercises, brisk walking, and recreational swimming), and everyday walking. Physical activity levels are classified as low, moderate, or high based on metabolic energy expenditure (metabolic equivalent of task, or MET) per minute per week.

The intensity of physical activity was expressed using metabolic equivalents (METs). MET equals the metabolic rate at work divided by the metabolic rate at rest. One MET equals one kcal/kg/hour and represents the energy required to sit quietly. Moderately active individuals require four times more calories, whereas vigorously active individuals require eight times more. Hence, time spent on moderate activities was assigned 4 METs, whereas time spent on vigorous activities was assigned 8 METs [16].

The MET-minute score is calculated by multiplying the MET value by the duration in minutes and the number of days. The walking duration is multiplied by a metabolic equivalent of 3.3 to obtain the walking score. A value of 4 METs is used for moderate physical activity, while 8 METs are used for vigorous physical activity.

Total MET-minutes of physical activity per week = MET-minutes of walking + MET-minutes of moderate activity + MET-minutes of vigorous activity

The levels of physical activity were then classified into three categories [16]:

1. Low level of physical activity (< 600 MET-min/week);
2. Moderate level of physical activity (600-3000 MET-min/week);
3. High level of physical activity (> 3000 MET-min/week).

Assessment of aerobic power

A one-mile submaximal test was used to evaluate the aerobic power of the participants. Their weight was recorded first. They were then instructed to walk for five minutes to warm up. After that, they were instructed to jog a mile (1609 meters) on a track with maximal effort. A smartwatch monitored their heart rate. Their heart rate should not exceed 180 beats per minute during the test, which lasted at least 9 minutes. They started once the instructor said "go" and started the stopwatch. Once the participant stopped, the heart rate was measured, and the jog time was recorded to calculate the aerobic power (mL/kg/min) using the following equation [17].

100.5- (0.1636× weight in kg)- (1.438× the time it takes to jog 1 mile lightly)- (0.1928× heart rate at the end of the jog)

Assessment of anaerobic power

The Running-Based Anaerobic Sprint Test (RAST) is a method for measuring anaerobic power and capacity. It comprises six 35-meter sprints separated by a 10-second recovery period [18]. Before starting the test, each participant performed a warm-up for 10 to 15 minutes, followed by a sufficient recovery period of 10 minutes. The test was conducted as follows: each participant was asked to sprint back and forth six times at full pace over 35 meters on a flat, hard surface, pausing for 10 seconds after each sprint. Cones were used to mark out a 35-meter straight on the track. The duration of each sprint was recorded using a stopwatch. Then, the following equation was used to calculate anaerobic power:

Power output (Watts)= Weight (Kilograms) x (Distance (meters))^2÷ Time (Seconds)^3.

- Maximum power: the highest value
- Minimum power: the lowest value
- Average power: is equal to the sum of all six values ÷ 6

Assessment of fatigue index

The fatigue index is the rate of power decline in the participant's performance. The fatigue index was assessed using the RAST test according to the following equation:

Fatigue Index= (maximum power - minimum power) ÷ Total time of 6 sprints

All measurements were taken in the late luteal phase to avoid variance among subjects. The session began with an assessment of aerobic power, followed by an assessment of anaerobic power, with a 20-minute break in between.

Statistical analysis

Descriptive statistics, including mean, standard deviation, minimum, maximum, median, interquartile range, and frequency, were used to present the measured variables. As the data were not normally distributed, non-parametric statistics were applied. A chi-squared test was used to investigate the association between PMS severity, physical activity, and dysmenorrhea. The Kruskal-Wallis test compared the median BMI values between females with mild, moderate, and severe PMS. This was followed by a Mann–Whitney U test to identify significant differences between each pair of categories. Spearman's rank correlation coefficient was used to evaluate the correlation between PMS severity and other variables. The significance level was set at $p < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 25, for Windows (IBM SPSS, Chicago, IL, United States).

Results

One hundred females with premenstrual syndrome participated in this study, with a mean age of 27.1 ± 4.98 years and a mean BMI of 26.4 ± 4.5 kg/m². Their mean age of menarche was 12.34 ± 1.33 years, and the duration of their menses was 5.33 ± 1.24 days. Fifty-three percent had dysmenorrhea, and 60% of participants were single. Twenty-nine percent were students, while 71% were employees.

Regarding PMS, 16%, 60%, and 24% of participants had mild, moderate, and severe PMS, respectively. For the physical activity (PA) level, 51% of females had low PA, 39% had moderate PA, and 10% had high PA. There was a significant association ($p < 0.05$) between PA and PMS severity. Severe PMS was associated with a low PA level compared to subjects with moderate or high physical activity. There was also a significant association ($p < 0.05$) between dysmenorrhea and PMS and no significant association ($p > 0.05$) with marital status (Table 1).

Females with severe PMS have a median BMI of 28.02 with an interquartile range of 32.91-25.77. Females with moderate PMS have a median BMI of 25.31 with an interquartile range of 26.89-23.11. Females with mild PMS have a median BMI of 25.04 with an interquartile range of 28.21-23. Subjects with severe premenstrual syndrome had a significantly higher BMI than subjects with mild premenstrual syndrome ($p = 0.04$) and moderate premenstrual syndrome ($p = 0.003$). At the same time, females with mild and moderate PMS showed no significant difference ($p = 0.82$).

Regarding aerobic capacity, the mean difference between mild and moderate PMS was -1.81, the mean difference between mild and severe PMS was 0.82, and the mean difference between moderate and severe PMS was 2.63. There was no significant difference in aerobic capacity among mild, moderate, and severe PMS groups ($F = 2.89$, $p > 0.05$) (Table 2).

Females with mild, moderate, and severe PMS showed no significant difference in average anaerobic power ($p > 0.05$) (Table 3).

Regarding the fatigue index, our results revealed a significant difference among females with mild, moderate, and severe PMS ($p < 0.05$). Table 4 shows a non-significant correlation (rho = 0.001, $p > 0.05$) between PMS severity and the fatigue index.

Discussion

This study investigated the relationship between lifestyle factors and PMS severity among Egyptian females. Regarding physical activity (PA), our results showed a significant association ($p < 0.05$) between physical activity and PMS severity. A larger percentage of females suffering from severe PMS exhibited low physical activity levels (79.2%)

Table 1. Association of premenstrual syndrome severity, physical activity, marital status, working status, and dysmenorrhea

Variables		Premenstrual syndrome			χ^2 value	p-value
		Mild (N= 16)	Moderate (N = 60)	Severe (N = 24)		
Physical activity	Low	4 (25%)	28 (46.7%)	19 (79.2%)	16.1	0.002*
	Moderate	8 (50%)	28 (46.7%)	3 (12.5%)		
	High	4 (25%)	4 (6.7%)	2 (8.3%)		
Marital status	Single	12 (75%)	37 (61.7%)	11 (45.8%)	3.57	0.16NS
	Married	4 (25%)	23 (38.3%)	13 (54.2%)		
Working status	Student	4 (25%)	21 (35%)	4 (16.7%)	2.94	0.23NS
	Employee	12 (75%)	39 (65%)	20 (83.3%)		
Dysmenorrhea	Yes	0 (0%)	32 (53.3%)	21 (87.5%)	29.51	0.001*
	No	16 (100%)	28 (46.7%)	3 (12.5%)		

χ^2, Chi-squared value; *p-value < 0.05; NS: non-significant; *: significant

Table 2. The aerobic capacity among different PMS categories

Premenstrual syndrome	Mean± SD	Min.	Max.	MD		95%, CI	p-value
Mild (n=16)	29.53 (± 4.41)	23.62	39.31	Mild-Moderate	-1.81	-5.29 to 1.67	0.63
Moderate (n=60)	31.25 (±5.34)	21.49	43.23	Mild-severe	0 .82	-3.02 to 4.65	1.00
Severe (n=24)	28.56 (±4.24)	21.79	38.57	Moderate-severe	2.63	- 0.15 to 5.40	0.07

SD: Standard deviation; Min, Minimum; Max: Maximum; MD: Mean difference; CI: Confidence interval; * p-value < 0.05

Table 3. Descriptive statistics of the power of the study group

Power (Watt)	Mean ±SD	Maximum	Minimum	Median	IQR
Maximum	3.83 ± 3.34	12.8	0.5	2.1	6.2-1.15
Minimum	2.11 ± 1.76	6.3	0.3	1.2	3-0.8
Average	2.87 ± 2.41	9.3	0.4	1.6	4.75-1
Median (IQR)					
Power (Watt)	**Mild premenstrual syndrome**	**Moderate premenstrual syndrome**	**Severe premenstrual syndrome**	**Kruskal-Wallis H**	**p-value**
Maximum	5.3 (8.9-1.32)	1.5 (4.52-1.1)	4.15 (6.2-1.4)	4.22	0.12NS
Minimum	1.9 (4.05-0.72)	1.2 (2.3-0.8)	2.45 (4.1-0.9)	4.36	0.11NS
Average	2.85 (6.05-1.02)	1.4 (2.8-0.9)	3.4 (4.9-1.02)	5.14	0.07NS

* p-value < 0.05; NS: non-significant; SD, Standard Deviation; IQR, Interquartile range

compared to those with moderate and high physical activity levels (12.5% and 8.3%, respectively). A lower percentage of subjects with moderate and severe PMS had high physical activity levels (6.7% and 8.3%, respectively).

The results can be explained by PA improving circulation and venous return, which is associated with decreased water retention and reduced local concentrations of inflammatory substances and prostaglandin levels. These effects may relieve

Table 4. Comparison between median values of fatigue index between mild, moderate as well as severe premenstrual syndrome

Fatigue index				
Median (IQR)			Kruskal-Wallis H	p-value
Mild premenstrual syndrome	Moderate premenstrual syndrome	Severe premenstrual syndrome		
0.013 (0.045-0.002)	0.002 (0.014-0.001)	0.012 (0.015-0.003)	7.19	0.02*

Mann–Whitney U test		
Premenstrual syndrome	**U-value**	**p-value**
Mild - Moderate	308	0.02*
Mild – Severe	170.5	0.55NS
Moderate – Severe	521	0.04*

U-value: Mann- Whitney test value; *p-value: < 0.05; IQR: Interquartile range; Kruskal-Wallis H: Kruskal-Wallis test value

PMS symptoms such as abdominal and pelvic pain and backache [19]. Exercise boosts muscle oxygenation and endorphin levels, improving mood and emotional status [6]. The current study's results are supported by Pearce et al., who concluded that PMS incidence was high in the low physical activity group, attributing this to the development of new technologies that deprived females of the benefits of exercise [20]. Colenso et al. found that exercising women had fewer PMS symptoms than sedentary women [21]. Additionally, Kawabe et al. concluded that women with high PA had lower PMS symptom scores [22].

In contrast, previous studies concluded that high-intensity activities contributed to menstrual-related disorders and a high prevalence of PMS symptoms in female athletes due to increased stress and fatigue related to high-level activities [11, 12]. While Sanchez et al. reported no relation between physical activity and either the prevalence or severity of PMS, they interpreted their results as indicating that the correlation between premenstrual symptoms and physical activity level is complex and multifactorial [23]. Our study also showed no significant difference in aerobic capacity among females suffering from mild, moderate, and severe PMS ($F = 2.89$, $p > 0.05$). Sabaei et al. contradicted the current study, revealing a significant negative correlation between the incidence of PMS and aerobic power ($r = -0.71$; $p < 0.05$). The discrepancy can be attributed to individual differences, cultural variations, and negative attitudes towards menstruation. Consequently, limitations on how women respond to their menstrual cycles can explain the results [13].

Regarding anaerobic power, there was a non-significant difference ($r = 0.076$, $p > 0.05$) between females with mild, moderate, and severe PMS. This result could be due to the fact that all participants were non-athletes. This finding aligns with studies by Chen et al. [12] and Carmichael et al. [24], who concluded that there is no statistically significant correlation between anaerobic power and PMS.

Regarding the fatigue index, our results revealed a non-significant correlation (rho = 0.001, $p > 0.05$) between the fatigue index and PMS severity. This result may be explained by the non-significant difference in anaerobic power between females suffering from mild, moderate, and severe PMS.

Current results revealed a significant association between dysmenorrhea and PMS, with 53% of women with PMS suffering from dysmenorrhea. This finding aligns with previously reported prevalence rates of 65.9% [25] and 71% [26]. Our study also concurs with a study that showed the scoring of dysmenorrheal pain severity in relation to premenstrual symptoms was highly significant ($p < 0.001$). The strong association between PMS and dysmenorrhea might be due to disturbances in steroid production [27]. Dysmenorrhea and PMS may have shared biochemical etiologies, including prostaglandins, which could explain why many women experience both conditions [28].

For BMI, females with severe PMS had higher BMI values compared to females with mild and moderate PMS ($p < 0.05$). These findings may be explained by the fact that adipose tissue converts androgens into estrogens. Additionally, there is a decreased ability of estrogens to attach to sex hormone-binding globulin (SHBG) in obese women, leading to increased serum-free estradiol levels [29]. Increased adiposity may also contribute to vitamin D deficiency [30], which can lead to dysregulation of the renin-angiotensin-aldosterone system (RAAS), potentially causing fluid retention [31]. Conversely, PMS may be considered one of the causes of a sedentary lifestyle and isolation, leading to increased obesity [32]. These points require further research for clarification.

There was agreement with the current results in previous studies [33, 34, 35]. Other studies, on the other hand, found a poor correlation [36] or no association [37] between BMI and PMS, or even the waist-to-hip ratio (WHR) and waist-to-height ratio (WTHR) [38]. Furthermore, Shamnani et al. reported a higher PMS prevalence (67.8%) among students with a normal BMI [39].

Our results revealed no significant association between marital status and PMS severity ($p > 0.05$). These findings are supported by Sadr et al., who reported no statistical difference in PMS between married and single groups ($p > 0.05$). They concluded that marital status is not a significant social factor in this syndrome [40].

This study has several strengths. Aerobic and anaerobic power measurements were conducted during the late luteal phase and at the same time of day (morning) to avoid time-of-day differences in anaerobic performance, ensuring more precise results. Valid and reliable questionnaires were used for the evaluative procedures. Additionally, the calculated power analysis is another strength of the study.

However, some factors limit this study. Pain tolerance varies between individuals, and psychological status and environmental factors may affect the evaluative procedures and participants' responses.

Conclusions

This study highlighted the physical activity level and demographic profile of a cohort of Egyptian females suffering from PMS. The results showed that lower physical activity and a higher BMI are associated with severe PMS. Furthermore, dysmenorrhea is associated with PMS. Therefore, being physically active and maintaining a BMI within a normal range can effectively decrease the severity of PMS. Additionally, there is a need for awareness programs about PMS and its associated factors, as well as holistic coping strategies to manage such cases.

Data Availability Statement

The data are available on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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ORIGINAL ARTICLE

Effect of small-sided game versus high-intensity interval training method in increasing anaerobic endurance in youth football athletes (15-17 years)

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Abstract

Background and Study Aim Small-sided games and high-intensity interval training programs are efforts to improve the anaerobic endurance of soccer players for optimal performance. However, training programs are often less effective. Therefore, this study aims to examine the effect of modified small-sided games and high-intensity interval training programs on improving anaerobic endurance and to compare the effectiveness of small-sided games versus high-intensity interval training results.

Material and Methods Thirty players aged 15-17 participated in the study. The research design used was a pre-experimental two-group pretest-posttest. The instrument adopted was the running-based anaerobic sprint test. Data were analyzed using paired sample t-tests to determine the effect of the training program, and independent t-tests were conducted to determine the effectiveness of small-sided games versus high-intensity interval training methods.

Results The results of the data normality test showed a significance value greater than 0.05, indicating that the data were normally distributed. The effect of the small-sided games training program and high-intensity interval training was tested using paired sample t-tests. The significance values were 0.00 for small-sided games and 0.27 for high-intensity interval training, indicating an increase in anaerobic endurance performance. The independent t-test comparing small-sided games and high-intensity interval training obtained a significance value less than 0.05, specifically 0.83, indicating no significant difference in results between the two methods.

Conclusions The study's findings showed that both small-sided games and high-intensity interval training programs significantly improved anaerobic endurance performance. However, the comparison of the effectiveness of the two methods did not show a significant difference. Both methods are equally effective in improving anaerobic endurance. These results underline that small-sided games and high-intensity interval training can be used to enhance anaerobic endurance performance.

Keywords: small-side games, hight-intensity interval training, physique, anaerobic, football.

Introduction

Many soccer training programs fail to effectively enhance the anaerobic endurance of players. This leads to suboptimal performance on the field. Traditional methods often lack the intensity and specificity required for significant improvement. This issue is particularly pronounced in the training of adolescent athletes. Properly tailored programs are essential for their development.

The optimisation of ideal modern football performance involves many aspects, including technique, tactics, and endurance capacity [1]. Physical aspects are critical for success in football. The assessment of physical aspects is crucial not only for adult athletes but also for adolescent athletes to achieve optimal performance [2]. Physicality is essential and must be continuously developed in football [3]. It serves as the main foundation of training [4, 5] to increase the success of technical, tactical, and strategic aspects [6].

Given the intensive nature of football, which requires consistent performance throughout the match [7], effective training variations are necessary to maintain physical readiness. Extensive studies have been conducted on training methods to improve physical aspects [8, 9]. These studies help find innovative solutions for training athletes. Exercises such as interval training and small-sided games (SSG) are frequently used as alternatives to enhance anaerobic energy metabolism. These exercises support essential movements in football, such as running, jumping, and changing direction [10].

Small-sided games (SSG) are a revolutionary form of training conducted in a small area with modified rules [11, 12]. SSG training is designed with attention to player area, field size, number of players, phase type, work and rest breaks, game rules, the inclusion or exclusion of goalkeepers, unpredictable player performance stimuli, and coach

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feedback [8]. This approach aims to modify the type of training regardless of age, gender, experience, and level of competition [8, 11]. Previous research states that SSG training involves real motion actions and technical awareness to improve youth football-specific functions and skills [13, 14]. In addition, SSG forces players to work extra hard and exhibit play under pressure, involving physiological demands and great attention that triggers fatigue [13, 15]. Thus, SSG is widely used to facilitate the improvement of players' physical and physiological performance under high pressure [16].

High-intensity interval training (HIIT), one of the most popular innovative exercise methods, adopts an intense and intermittent form of exercise with interspersed rest periods. HIIT usually provides time efficiency and significant improvements in both aerobic and anaerobic performance [17, 18]. Previous research suggests that HIIT can increase anaerobic and aerobic activity, enhance cardiopulmonary capacity, and promote body fat loss [7, 19].

Several studies convey the differences between the small-sided games (SSG) training method and high-intensity interval training (HIIT). SSG training, carried out using a ball in a small area, aims to improve technical, tactical, and motivational abilities [20]. In contrast, HIIT, conducted without a ball, focuses on increasing endurance capacity [21]. Additionally, many studies have compared SSG and HIIT training methods for team sports such as football [1, 13, 14].

An analysis of the research has shown that few studies investigate the effectiveness of training methods between small-sided games (SSG) and high-intensity interval training (HIIT) for adolescent football players. Therefore, there is an obvious need to continue research in this direction.

In this context, the first hypothesis is that both SSG and HIIT methods influence the improvement of anaerobic endurance performance. The second hypothesis is that SSG and HIIT methods have the same effectiveness in improving anaerobic endurance performance. Therefore, this study aims to examine the effect of modified small-sided games and high-intensity interval training programs on improving anaerobic endurance and to compare the effectiveness of small-sided games versus high-intensity interval training results.

Materials and Methods

Participants

Thirty youth football players participated in the study (aged 15-17 years), which was conducted in Yogyakarta, Indonesia. All players belonged to the FC UNY Academy club and had competed at the regional level for their age group. The players were divided into two groups: the small-sided games (SSG) group (n=15) and the high-intensity interval training (HIIT) group (n=15). All players were informed about the study's procedures, requirements, benefits, and risks.

Research Design

This study used a pre-experimental design, specifically a two-group pretest-posttest design. In the initial stage, the players underwent a pretest before receiving any treatment or intervention. After that, the players were involved in the small-sided games (SSG) based training method for group one and the high-intensity interval training (HIIT) program for group two to improve anaerobic endurance. In the final stage, the players underwent a posttest. The results of the pretests and posttests of each group were then calculated to determine the improvement before and after the SSG and HIIT exercise programs. After comparing the pretest and posttest results within each group, comparisons were made between the SSG and HIIT groups.

Data were collected using valid and specific instruments. Anaerobic endurance performance ability was assessed using the running-based anaerobic sprint test (RAST) [22]. The RAST has a validity of 0.897 and a reliability of 0.919 [23].

Protocol Design

The implementation phase of the training program for each group was conducted three times a week (Monday, Wednesday, and Friday) over the six-week training period. Each training session started with a warm-up phase, followed by a game/program implementation phase, a tactical phase, and ended with a cool-down phase. The program was consistently applied throughout the study period. Table 1 shows the implementation of the program's small-sided games (SSG) phase, and Table 2 shows the implementation of the high-intensity interval training (HIIT) phase. In group one (SSG), the intensity, repetitions, distance, and rest time varied each week. For group two (HIIT), the intensity, repetitions, and rest periods also varied each week, reflecting changes in competition demands.

Statistical Analysis

Statistical data analysis of the study used the Shapiro-Wilk test to assess data normality. Differences in pretest and posttest results within each group were compared using paired sample t-tests. The statistical significance of the study was set at $p < 0.05$. In addition, an independent t-test was conducted to compare the training effects between group one (small-sided games, SSG) and group two (high-intensity interval training, HIIT). Statistical data analysis was performed using SPSS version 25.0 for Windows.

Results

The effectiveness of the small-sided games (SSG) and high-intensity interval training (HIIT) programs was assessed using the Paired Sample T-test. Figure

Table 1. Small-sided games program

Week	Meeting	Type of SSG activity	Training description
1	1-3	5 vs 5	Repetitions: 3; One repetition time: 2 minutes; Rest between reps: 2 minutes (1:1); Sets: 3; Rest between sets: 4 minutes (1:2); Area: 20x10 meters; Intensity: 75%
2	4-6	4 vs 4	Repetitions: 3; One repetition time: 2 minutes; Rest between reps: 2 minutes (1:1); Sets: 3; Rest between sets: 4 minutes (1:2); Area: 15x10 meters; Intensity: 80%
3	7-10	3 vs 3	Repetitions: 3; One repetition time: 2 minutes; Rest between reps: 2 minutes (1:1); Sets: 4; Rest between sets: 4 minutes (1:2); Area: 15x10 meters; Intensity: 80%
4	11-13	2 vs 2	Repetitions: 3; One repetition time: 1 minute; Rest between reps: 1 minute (1:1); Sets: 4; Rest between sets: 3 minutes (1:3); Area: 15x10 meters; Intensity: 90%
5	14-16	1 vs 1	Repetitions: 4; One repetition time: 1 minute; Rest between reps: 1 minute (1:1); Sets: 4; Rest between sets: 3 minutes (1:3); Area: 10x10 meters; Intensity: 95%
6	17-20	3 vs 3	Repetitions: 4; One repetition time: 2 minutes; Rest between reps: 2 minutes (1:1); Sets: 4; Rest between sets: 4 minutes (1:2); Area: 10x10 meters; Intensity: 80%

Table 2. High-intensity interval training program

Week	Meeting	Reps	Training description
1	1-3	6	Rest between reps: 1:2; Area: 30m long x 13m wide; Intensity: 75%
2	4-6	6	Rest between reps: 1:2; Area: 30m long x 13m wide; Intensity: 80%
3	7-10	6	Rest between reps: 1:2; Area: 30m long x 13m wide; Intensity: 80%
4	11-13	5	Rest between reps: 1:3; Area: 30m long x 13m wide; Intensity: 90%
5	14-16	5	Rest between reps: 1:3; Area: 30m long x 13m wide; Intensity: 95%
6	17-20	6	Rest between reps: 1:2; Area: 30m long x 13m wide; Intensity: 80%

Table 3. Pretest-posttest normality test for small-sided games and high-intensity interval training

Group	Variable	n	Sig.
Pre-test	SSG	15	0.848
Pre-test	HIIT	15	0.730
Post-test	SSG	15	0.703
Post-test	HIIT	15	0.146

Note: Normality data using the Shapiro-Wilk test for small-sided games (SSG) and high-intensity interval training (HIIT) are generally distributed with significance > 0.05.

Table 4. Paired sample test results of small-sided games and high-intensity interval training

Variable		Mean	Std. Deviation	Sig.
Pair 1	Pre-test SSG	35.8940	1.96545	0.004
	Post- test SSG	34.7353	1.30882	
Pair 2	Pre-test HIIT	35.3880	1.90705	0.278
	Post- test HIIT	34.8460	1.61980	

Note: Results between pretest-posttest small-sided games (SSG) 0.004 and high-intensity interval training (HIIT) 0.278, showing significance <0.05, which means there is a difference in results between the pretest and posttest.

1 shows the average values of SSG vs. HIIT pretest and posttest results.

The results of the SSG and HIIT pretest-posttest normality test on anaerobic endurance are shown in Table 3.

The data were normally distributed with a significance value greater than 0.05. Table 4 presents the paired sample t-test results to evaluate the effect

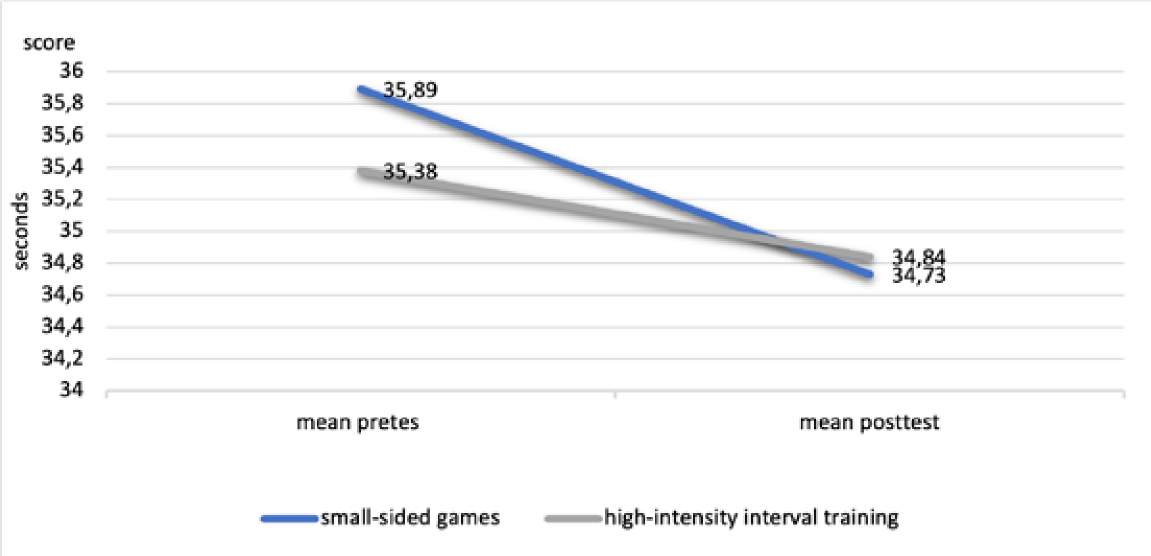

Figure 1. Descriptive data mean pretest-posttest small-sided games and high-intensity interval training

Table 5. Independent samples t-test between small-sided games and high-intensity interval training

Variable	Equality of Variances		t-test for equality of Means			
	f	Sig.	t	df	Sig. (2-tailed)	Mean difference
Anaerobic	0.403	0.501	-0.206	28	0.838	-0.11067

Note: Independent sample t-test significance value <0.05. The results showed no significant difference between small-sided games vs. high-intensity interval training with a 2-tailed significance value of 0.838.

of the SSG and HIIT programs, showing significance values greater than 0.05, indicating an increase between pretest and posttest results. Furthermore, Table 5 compares the effectiveness of the SSG vs. HIIT programs using an independent t-test, with a significance value less than 0.05, indicating no significant difference between SSG and HIIT.

Discussion

The study's main objective was to evaluate the effects of small-sided games (SSG) and high-intensity interval training (HIIT) and to determine the effectiveness of SSG vs. HIIT training for adolescent football players. The study's novelty focused on modifying the area, duration, and frequency of SSG and HIIT methods and comparing the effectiveness of the two methods in football training.

The findings support the first hypothesis, showing a significant increase (sig. < 0.05) in anaerobic endurance performance (Table 4). This indicates that the designed methods successfully improve anaerobic endurance. The findings align with previous research, suggesting that the SSG method is suitable and beneficial for early-stage physical, technical, and change-of-direction training in football [20]. Additionally, other studies suggest that the HIIT method improves young players' Vo2max, aerobic, and anaerobic performance [21].

Then, the results related to the effectiveness of SSG vs. HIIT showed no significant difference (sig. > 0.05), indicating that both methods have the same level of effectiveness in improving anaerobic endurance performance and do not show a dominant difference in results. Similar research also highlighted that SSG and HIIT methods are equally effective in maintaining the physical fitness of youth football players over several weeks [14]. Furthermore, Arslan [13] confirmed that SSG and HIIT methods were equally effective in improving body composition, aerobic fitness, and anaerobic fitness in youth football players.

Specifically, this study was designed to test SSG vs. HIIT methods on anaerobic endurance performance. However, neither method showed dominant results in either group. This may be due to the fact that both methods are running-based exercises. SSG involves running-based exercises using a game dynamic that includes intervention from opponents [24], with durations ranging from 45 seconds [25] to four minutes [26] and several repetitions from two to ten. It also uses a smaller area format to provide high-intensity running demands, such as sprints [27,28] with rapid excitatory changes [29,30]. In comparison, HIIT consists of repeated short-interval sprints, long intervals, and sprint intervals [31], with a work-to-rest ratio of 1:1 [25]. Thus, comparing the effects of these two methods is challenging. Based on a meta-analysis review, the performance of HIIT is similar to SSG principles, involving frequent direction changes, acceleration, and deceleration [32].

The SSG and HIIT methods showed improved anaerobic endurance performance after receiving their respective treatments. Therefore, the study's final results are expected to be valid and provide valuable guidance for coaches and athletes, especially in the field of football.

The limitation of this research is the small sample size of adolescent male athletes, which does not accommodate more comprehensive results regarding gender, competition level, or different age groups. Future studies are recommended to use a broader range of subjects and to apply SSG and HIIT methods that consider player profiles, including gender and competition levels.

Conclusions

Based on the research findings, both SSG and HIIT showed significant results (significance > 0.05) for the training program effect and insignificant results (significance < 0.05) for the effectiveness between SSG and HIIT. This means that both methods are equally effective in improving anaerobic endurance performance in adolescent football players. Therefore, these findings can be considered by coaches in developing various training programs, as they can improve anaerobic endurance performance in youth football. Additionally, the findings of this study provide an essential foundation for future research to encourage more comprehensive studies exploring various populations and genders.

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ORIGINAL ARTICLE

Comparative analysis of hand dynamometer measurements across different arm positions: implications for rehabilitation and functional assessment

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Abstract

Background and Study Aim Grip strength is a crucial measure of human physical capability, affecting activities from daily tasks to athletic performance. Variations in arm position during grip strength measurement may influence the results, which has significant implications for both rehabilitation and functional assessment. This study explores the impact of different arm positions on grip strength to enhance understanding of human biomechanics and inform rehabilitation and sports training practices.

Material and Methods Forty right-handed male volunteers (mean age 18.27 ± 0.90 years) participated in the study. Grip strength was measured using a CAMRY Model: EH101 hand dynamometer. Measurements were taken across four arm positions: seated with elbow extension, 90-degree elbow flexion, 90-degree elbow flexion with pronation, and 90-degree elbow flexion with supination. Each position was tested three times. The highest recorded value for each position was used for analysis.

Results The dominant right hand exhibited higher grip strength across all positions compared to the non-dominant left hand. Significant differences were noted, with the greatest grip strength in the extension position. Statistical analysis using paired t-tests indicated significant differences ($p < 0.001$) between the right and left hands across all positions. Pearson correlation coefficients highlighted strong relationships between different arm positions. Multiple linear regression analysis showed significant predictors of grip strength variability based on arm position, age, and BMI.

Conclusions Arm position significantly influences grip strength performance, underscoring the importance of standardized positioning in ergonomics. Standardizing arm position can optimize performance and mitigate injury risks in activities requiring robust grip strength. These findings have practical implications for rehabilitation protocols, sports training programs, and ergonomic assessments. The results emphasize the need for consistency in grip strength evaluations to ensure accurate and reliable results.

Keywords: grip strength, arm position, biomechanics, rehabilitation, functional assessment, athletic performance.

Introduction

The foundational aspect of human physical capability, grip strength, holds pivotal significance across a spectrum of activities, from mundane tasks to athletic pursuits. The ability to exert and maintain force through the hand and fingers is influenced by various factors, with the positioning of the arm during grip exertion being a key determinant [1, 2, 3]. A recent study showed that maximal isometric grip strength is influenced by gender, handedness, posture, and population [4]. It also highlighted the need for gender-, population-, and posture-specific grip strength data for clinical and industrial applications.

Beyond its role in manual dexterity, grip strength is intricately linked to overall muscular strength, functional independence in daily activities, and certain health outcomes. As a fundamental metric for assessing muscular strength and upper extremity functionality, hand grip strength transcends diverse domains, including clinical diagnosis, physical fitness evaluation, sports performance, and occupational health [4, 5]. The importance of grip strength is accentuated in sports, where it directly influences an athlete's control, performance, and injury prevention, particularly in activities such as weightlifting, rock climbing, and martial arts [6]. Consequently, grip strength training and evaluation have become integral components in sports conditioning and injury prevention programs.

The ramifications of grip strength extend to occupational environments, particularly in jobs involving manual labor or the manipulation of heavy objects [7, 8]. Assessing and enhancing grip

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strength play a crucial role in mitigating the risk of work-related injuries, optimizing job performance, and guiding the design of ergonomic interventions. In the medical arena, hand grip strength serves as a multifaceted indicator, evaluating an individual's ability to perform daily tasks and assessing upper extremity function. Recognizing its role as a marker of overall muscular strength, grip strength has become indispensable in evaluating health status, bone density, and body composition [8].

Measuring hand grip strength proves beneficial in assessing individuals with difficulties in daily tasks, evaluating upper extremity function integrity, and gauging the success of hand rehabilitation techniques [9, 10]. However, the influence of various factors on grip strength necessitates standardized techniques for accurate evaluation. Presently, there is a lack of consensus regarding the ideal shoulder, elbow, and wrist positions for assessing hand grip strength, highlighting the need for a standardized approach to enhance the validity of evaluations [11, 12, 13].

Despite numerous studies across various age groups and populations, significant gaps remain in the understanding of the influence of different arm positions on grip strength. Addressing these issues is crucial for improving the accuracy and reliability of grip strength assessments in clinical, occupational, and sports settings. This study explores the impact of different arm positions on grip strength to enhance understanding of human biomechanics and inform rehabilitation and sports training practices.

Materials and Methods

Participants

A total of forty male volunteers, aged 18.27 ± 0.90 years, were enrolled (Fig. 1). A thorough evaluation of medical records was performed, which included a review of diagnostic reports and participant interviews. Eligible subjects were informed about the experimental procedures, and informed consent was obtained, ensuring transparency and ethical compliance throughout the research. This study conformed to ethical guidelines and was initiated following the approval of the Research Ethical Committee at J.N. Medical College, Aligarh Muslim University (AMU), Aligarh, India (Ethical approval number: IECJNMC/943).

Inclusion Criteria. The inclusion criteria for participants in this study were meticulously defined to ensure the reliability and validity of the findings. Eligible participants had to be right-handed, with the right hand serving as their dominant hand. They needed to be capable of independently performing grip force measurements in four specified arm positions. Additionally, participants were required to be in good physical and mental health, free from any conditions that could impair their performance or the study's outcomes, such as limb deficiencies, limb deformities, or depression.

*Exclusion Criteria***.** The exclusion criteria for this study were established to eliminate potential confounding factors that could affect grip strength assessment. Participants were excluded if they had any neurologic or orthopedic conditions impacting grip strength. Those with a history of pathology or trauma to the upper extremity or neck region were also excluded. Additionally, individuals with ongoing injuries, illnesses, or pain affecting the upper limbs or any part of the body that could influence grip strength assessment were not considered for participation.

Outcome measure

The primary outcome measure was grip strength, quantified using a CAMRY Model: EH101 hand dynamometer, ISO 9001 certified by SGS, with a maximum bearing strength of 90kg/198lb. The dynamometer underwent professional calibration according to the manufacturer's specifications to ensure accuracy and consistency throughout the study.

Procedure

Preparation and Participant Briefing. Upon approval from the Research Ethical Committee at JN Medical College, AMU, Aligarh, and securing informed consent from each participant, the following preparatory steps were undertaken:

- *Demographic Data Collection.* Each participant's age, height, weight, and BMI were recorded using a stadiometer and an Omron weighing machine (MODEL HBF-212-IN).
- *Orientation Session.* Participants were briefed on the study's objectives, procedures, and the importance of accurate performance during grip strength measurements.

Grip Strength Measurement Setup. The hand dynamometer (CAMRY Model: EH101) was calibrated according to the manufacturer's specifications to ensure accuracy. Each participant's hand size was measured, and the dynamometer was adjusted to fit appropriately, ensuring that the device handle was positioned at the second knuckle.

Measurement Protocol. Grip strength was measured in four different arm positions for both hands (Fig. 2). Each measurement was performed three times per position, with a 30-second rest interval between trials to minimize fatigue effects. The highest value from the three trials was recorded as the maximal grip strength.

1. *Seated with Elbow Extension.*
    - *Positioning.* Participants sat on an armless straight-backed chair with shoulders in a neutral position and arms by their sides. The elbow of the tested arm was fully extended.
    - *Measurement.* Participants exerted maximum force on the dynamometer for 1 second upon demand.

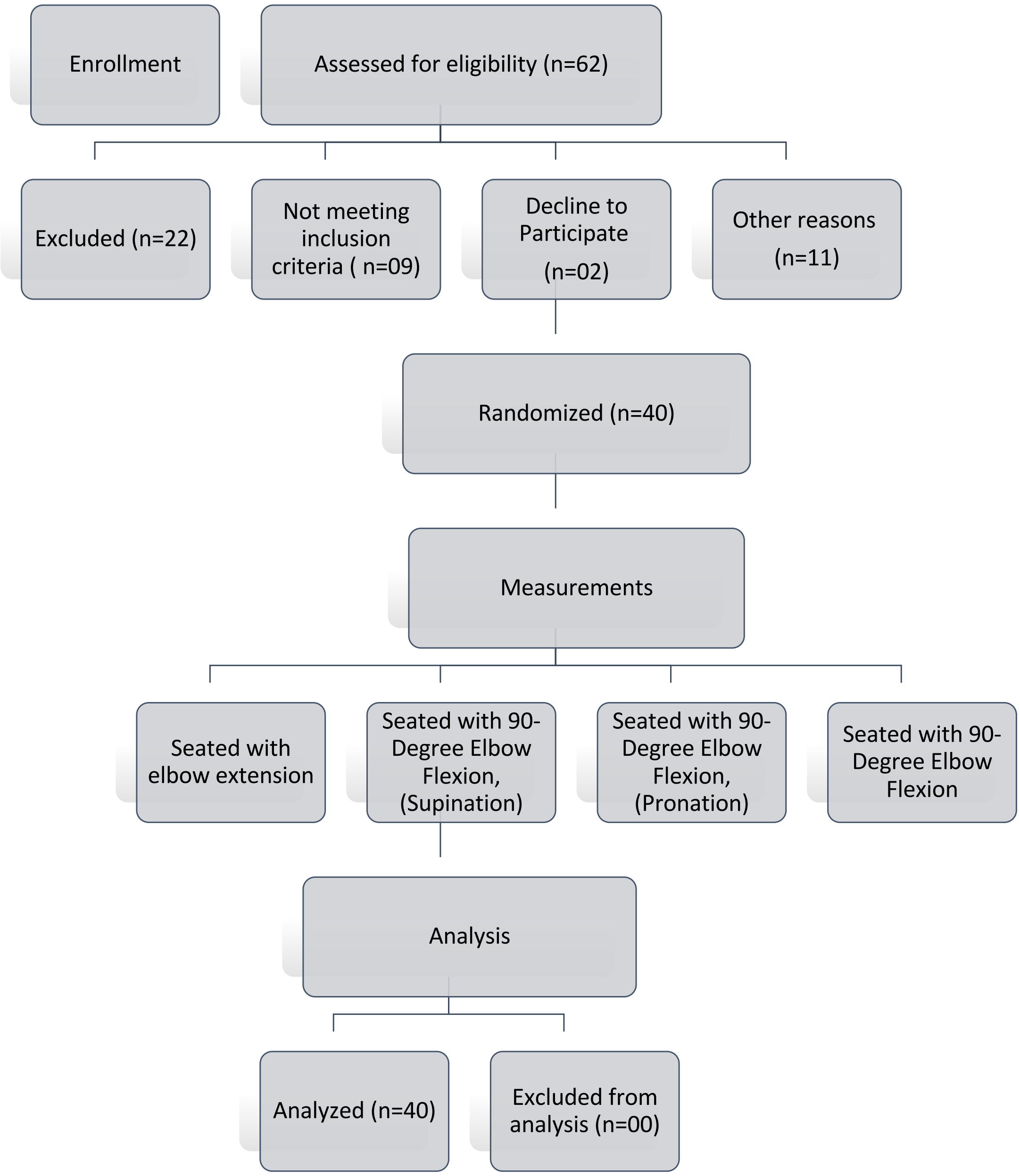

Figure 1. Flowchart showing the number of participants assessed for eligibility, randomized and analyzed during the study.

Figure 2. Four distinct arm positions

2. *Seated with 90-Degree Elbow Flexion.*
   - *Positioning.* Participants sat with shoulders in a neutral position and arms by their sides. The elbow of the tested arm was flexed at a 90-degree angle.
   - *Measurement.* Participants exerted maximum force on the dynamometer for 1 second upon demand.
3. *Seated with 90-Degree Elbow Flexion, Pronation.*
   - *Positioning.* Participants sat with shoulders in a neutral position and arms by their sides. The elbow of the tested arm was flexed at 90 degrees with the palm facing downwards.
   - *Measurement.* Participants exerted maximum force on the dynamometer for 1 second upon demand.
4. *Seated with 90-Degree Elbow Flexion, Supination.*
   - *Positioning.* Participants sat with shoulders in a neutral position and arms by their sides. The elbow of the tested arm was flexed at 90 degrees with the palm facing upwards.
   - *Measurement.* Participants exerted maximum force on the dynamometer for 1 second upon demand.

Measurement Guidelines.

- *Standardization.* The sequence of the four grip strength test positions was consistent for all participants.
- *Acclimatization.* Participants were allowed to perform submaximal efforts during initial attempts to familiarize themselves with the dynamometer and testing procedure.
- *Instruction.* Clear instructions and demonstrations were provided to ensure participants understood the correct technique and exerted maximal effort during each trial.

Data Recording and Quality Control.

- *Data Logging.* Grip strength values for each trial were logged immediately after measurement.
- *Error Minimization.* To reduce measurement error, participants were monitored closely to ensure they maintained the specified arm positions and exerted effort consistently across trials.

By implementing this systematic and standardized approach, the study aimed to capture reliable and valid grip strength data across different arm positions, contributing to a robust comparative analysis.

Statistical Analysis

Statistical analysis was performed using SPSS 23.0 to analyze variables such as age, weight, height, BMI, dominant hand, and grip strength across four distinct arm positions. Descriptive statistics were first computed to summarize participant demographics and baseline characteristics alongside grip strength measurements in each position. A paired t-test was then employed to evaluate significant differences in grip strength between the various arm positions within participants, assessing whether differences observed were statistically significant. Additionally, the Pearson correlation coefficient was calculated to examine relationships between grip strength measurements across different positions, aiming to elucidate any linear associations. A significance level of $p < 0.05$ was adopted to determine statistical significance, ensuring robust interpretation of findings. This approach underscored the study's methodological rigor and provided comprehensive insights into how varying arm positions affect grip strength, bolstering the validity and reliability of the results.

Results

The participants, forty young adults, have an average age of 18.27 years, a mean weight of 62.61 kg, and an average height of 159.30 cm (Tabl. 1). Their BMI values range from 19.08 to 31.22, with an average of 24.67, suggesting that most participants are within a healthy weight range, predominantly falling into normal to slightly overweight categories. This detailed anthropometric data ensures a representative sample, providing a solid basis for examining grip strength variations across different arm positions and hand dominances.

Table 2 shows significant differences in grip strength between the dominant right hand and the non-dominant left hand across various arm positions. The right hand consistently demonstrates higher grip strength, underscoring the dominance effect. This statistically significant difference highlights the importance of considering hand dominance in grip strength evaluations. Additionally, grip strength varies with arm position, with both hands showing their highest strength in extension and the lowest in supination. These findings indicate that arm position significantly impacts grip strength measurements. To ensure accurate and meaningful assessments, it is essential to standardize arm position and consider hand dominance.

Table 3 shows the paired sample t-test results comparing grip strength between the dominant right hand and the non-dominant left hand across various arm positions. The results reveal significant mean differences, with the right hand consistently exhibiting higher grip strength. This dominance effect is evident across all tested positions, highlighting the substantial impact of hand dominance on grip strength. Notably, the disparity in grip strength is most pronounced in pronation and least pronounced in flexion, suggesting that the degree of strength difference varies with arm position. These findings emphasize the need to account for hand dominance when assessing and interpreting grip strength in both clinical and

Table 1. Anthropometrics of the Participants

Anthropometric Measurements	N	Minimum	Maximum	Mean	SD
Age (y)	40	17.00	20.00	18.27	0.90
Weight (kg)	40	49.00	76.00	62.61	6.88
Height (cm)	40	152.00	180.00	159.30	5.69
BMI*	40	19.08	31.22	24.67	2.43

Note. M, Mean; SD, Standard deviation; PCT, percentile values. *Calculated as weight in kilograms divided by height in meters squared.

Table 2. Grip Strength (in Kg) in Various Conditions among Different Hands

Arm Position						
N	Arm	Extension	Flexion	Pronation	Supination	P-value
		M ± SD	M ± SD	M ±SD	M ± SD	
40	Right *	40.96 ± 4.54	38.96 ±6.17	38.42 ±4.44	37.05 ±4.60	<0.001
40	Left	36.14 ±3.96	34.82 ± 3.51	32.96 ±3.08	32.09 ±3.89	<0.001

Note: The data is represented as M (SD); *Means the right hand is dominant.

Table 3. Paired Sample t-Test Results for Mean Differences in Right and Left Arm Positions

Comparison	N	Mean Difference	Mean Difference	t-value	p-value
Right Extension -Left Extension	40	4.82	2.90	10.50	0.000 <0.05
Right Flexion -Left Flexion	40	4.14	5.40	4.85	0.000 <0.05
Right Pronation -Left Pronation	40	5.45	3.55	9.70	0.000 <0.05
Right Supination -Left Supination	40	4.96	3.04	10.32	0.000 <0.05

Table 4. Correlation results between different positions

Variable	Age	Weight	Height	RE	RF	RP	RS	LE	LF	LP	LS
Age	1	0.475*	0.153	-0.056	-0.037	0.155*	0.081	0.073	0.062	0.189*	0.070
Weight		1	0.465*	0.186	0.028*	0.141	0.219*	0.182	0.286*	0.283	0.066*
Height			1	0.239	0.019	-0.027*	0.152	0.168	0.222	0.056*	0.030
RE				1	0.596	0.821	0.818	0.775	0.724	0.552	0.681
RF					1	0.602	0.543	0.557*	0.491	0.401	0.533
RP						1	0.852	0.723*	0.702	0.605	0.771
RS							1	0.686*	0.675	0.652	0.757
LE								1	0.861	0.682	0.712
LF									1	0.769	0.697
LP										1	0.754
LS											1

Note. RE - right extension, RF - right flexion, RP - right pronation, Rs - right supination, Le - left extension, LF - left flexion, LP - left pronation, Ls - left supination; *Indicates a significant correlation at the level of 0.001.

research contexts.

Table 4 provides correlation coefficients between age, weight, height, and grip strength across various arm positions for both the dominant right hand and the non-dominant left hand, with significant correlations at the 0.001 level marked with an asterisk (*). The analysis reveals several key trends. Age shows a positive correlation with weight and modest positive correlations with grip strength in the pronation position for both hands. However, it has weak negative correlations with grip strength in the extension and flexion positions of the right hand, suggesting a slight decrease in grip strength in these positions with age within this young adult sample. Weight is strongly correlated with height and significantly positively correlated with grip strength in various positions for both hands, indicating that heavier individuals generally exhibit higher grip strength across most arm positions. Height shows significant positive correlations with grip strength in several positions for both hands, suggesting that taller individuals tend to have greater grip strength. However, there are weak negative correlations with grip strength in the right flexion and right pronation positions. For the dominant right hand, there are strong correlations between different grip strength positions, indicating consistency in performance across various arm positions. Similar patterns are observed for the non-dominant left hand, demonstrating robust internal consistency in grip strength measures. These findings underscore the importance of considering anthropometric factors such as age, weight, and height when assessing grip strength. The consistency of grip strength performance across different positions within each hand highlights the reliability of these measurements, which is crucial for ensuring accurate and meaningful evaluations in both clinical and research settings.

Table 5 presents findings from a multiple linear regression analysis investigating the impacts of arm postures, age, and BMI on grip strength. Significant differences were observed between right extension and right flexion, indicating a relationship in grip strength between these positions. However, other posture comparisons like right flexion versus right supination did not show significant differences, suggesting weaker associations between grip strength and these postures. Age and BMI were found to have no significant influence on grip strength in this study, indicating that within this sample, variations in these factors do not reliably predict differences in grip strength. The wide confidence intervals and p-values above 0.05 in several comparisons underscore the variability in grip strength data and highlight the complexities involved in predicting grip strength based solely on the variables assessed (Fig. 3). These insights emphasize the need for comprehensive assessments considering multiple factors in both clinical practice and research to ensure accurate evaluations of grip strength across diverse populations.

The following regression equations describe the relationships between various arm postures (predictor variables) and grip strength (dependent variable), derived from the multiple linear regression analysis. Grip Strength represents the predicted grip strength, while RE, RF, RS, and RP denote the grip strengths in right extension, right flexion, right supination, and right pronation, respectively. The term ε represents the error or residual term:

Model 1: Right Extension (RE) vs. Right Flexion (RF): $\text{Grip Strength}=0.555\times(RE-RF)+\varepsilon$

This equation signifies the effect of changing grip strength from right extension to right flexion, considering the coefficient 0.555.

Model 2: Right Flexion (RF) vs. Right Supination (RS): $\text{Grip Strength}=-22.851\times(RF-RS)+\varepsilon$ It illustrates

Table 5. Results of the Multiple Linear Regression Analysis

Name of predictor variable (Posture)	B	**95%ci**	**P value**
RE Vs RF	0.555	(-1.099, 0.011)	0.046
RF Vs RS	-22.851	(-602.541, 556.839)	0.587
RE Vs RS	54.694	(-524.996, 634.384)	0.587
RE Vs RP	156.763	(-728.763, 415.237)	0.832
RF Vs RP	-366.085	(-1060.474, 328.304)	0.269
RS Vs RP	-211.457	(-793.626, 370.712)	0.434
Age	0.588	(-1.369, 2.545)	0.560
BMI	2.937	(-5.488, 11.362)	0.510

Note. RE - right extension, RF - right flexion, RP - right pronation, Rs - right supination

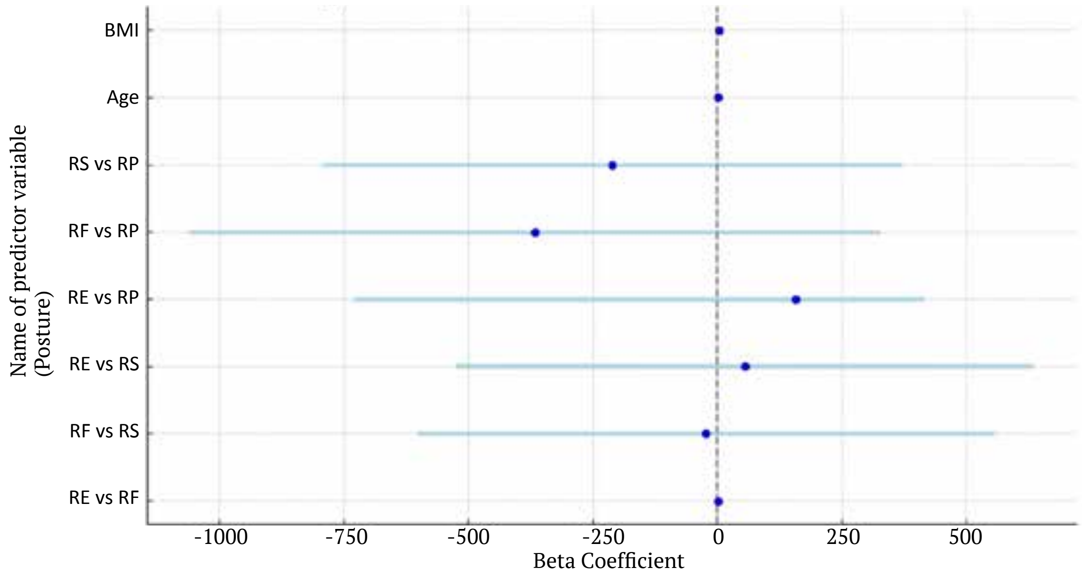

Figure 3. Regression coefficients (β) and their 95% confidence intervals. The vertical line at β=0 serves as a reference point.

the impact on grip strength when transitioning between right flexion and right supination, with a coefficient of -22.851.

Model 3: Right Extension (RE) vs. Right Supination (RS):Grip Strength=54.694 × (RE−RS) +ε

This equation shows how grip strength changes from right extension to right supination, adjusted by the coefficient 54.694.

Model 4: Right Extension (RE) vs. Right Pronation (RP):Grip Strength=156.763×(RE−RP)+ε

Describes the relationship between grip strength in right extension and right pronation, influenced by the coefficient 156.763.

Model 5: Right Flexion (RF) vs. Right Pronation (RP):Grip Strength=−366.085×(RF−RP)+ε

Indicates how grip strength varies from right flexion to right pronation, accounting for the coefficient -366.085.

Model 6: Right Supination (RS) vs. Right Pronation (RP):Grip Strength=−211.457×(RS−RP)+ε

Shows the impact on grip strength when transitioning between right supination and right pronation, with the coefficient -211.457.

Regression models equations summarize the relationships between different arm postures (predictor variables) and grip strength (dependent variable) based on the regression coefficients (β) obtained from the analysis. They provide a quantitative understanding of how changes in grip strength in one posture relative to another are expected, given the coefficients derived from the regression analysis.

Discussion

This study aimed to investigate variations in grip strength across different arm positions and hand dominances among young adults. The findings contribute valuable insights into how anthropometric factors and hand dominance impact grip strength, with implications for clinical and research applications.

Anthropometric data (Table 1) indicated that participants generally maintained a healthy weight, with a mean BMI of 24.67, characteristic of typical young adults and ensuring sample representativeness. Age, weight, and height variations were controlled to create a homogeneous group, reducing potential confounding effects on grip strength measurements.

Significant variations in grip strength across different sitting arm positions were observed, with the highest strength recorded during elbow extension for both hands and a noticeable decline in the supination position. This aligns with biomechanical principles attributing force production to muscle length-tension relationships and joint mechanics. [14, 15, 16]. These results are pertinent to clinical assessments, ergonomic interventions, and athletic training programs [14]. The study also identified substantial variations in grip strength across different sitting arm positions (extension, flexion, pronation, and supination). Grip strength was highest during elbow extension for both dominant and non-dominant hands, with a notable decrease observed in the supination position [15]. This aligns with existing literature underscoring the influence of muscle length-tension relationships and joint mechanics on force production [16].

The results of the study further confirmed substantial grip strength disparities between the right and left hands across all tested arm positions, underscoring the varying influence of hand dominance on grip strength due to differential muscle engagement and mechanical advantage in each position. The largest difference was observed during pronation, while the smallest was noted in flexion. These findings indicate that hand dominance exerts a varying influence on grip strength across different arm positions, likely due to differential muscle engagement and mechanical advantage inherent in each position. This phenomenon of hand dominance effect is well-documented in literature, attributed to habitual use and superior muscle conditioning of the dominant hand in daily activities [17]. The substantial disparity in grip strength between hands underscores the importance of considering hand dominance in clinical assessments and rehabilitation protocols [18].

Correlation analysis revealed significant relationships between age, weight, height, and grip strength. Weight showed a strong positive correlation with grip strength across most arm positions, suggesting that individuals with higher body weight tend to exhibit greater grip strength. Height also demonstrated positive correlations with grip strength, albeit to a lesser extent. These findings align with biomechanical principles indicating that larger body size generally contributes to increased muscle mass and strength. Notably, age exhibited a modest positive correlation with grip strength in the pronation position, but a weak negative correlation in extension and flexion positions, indicating a potential peak and subsequent decline in grip strength during young adulthood [19]. Grip strength typically declines with age due to muscle mass and musculoskeletal strength loss.

Our study introduced a novel arm posture – sitting with arms in supination – to assess its impact on grip strength compared to sitting with the elbow fully extended. Contrary to expectations, the supinated posture did not yield greater grip strength, likely due to reduced engagement of forearm muscles crucial for grip strength and gravitational effects [20].

The strong positive correlation observed across various arm postures highlights the integrated nature of muscle groups involved in grip strength. This suggests that alternative postures could be considered when the standard posture is impractical, with regression coefficients aiding in clinical applications [21].

Multiple linear regression analysis provided nuanced insights into factors influencing grip strength, including arm posture, age, and BMI. Our models confirmed age, weight, and BMI as significant predictors of grip strength, consistent with previous research [22]. Specifically, sitting with the elbow fully extended consistently resulted in higher grip strength values, supporting its standardization in clinical settings for accurate muscle strength assessment [22].

Interaction terms in our models revealed that age and posture significantly influence grip strength, suggesting older adults may experience varied grip strength outcomes based on posture during measurement. This aligns with prior research emphasizing standardized posture for reliable grip strength assessments [23, 24]. Diagnostic tests validated the robustness of our regression models, showing normality in residual plots and absence of multicollinearity among predictors (VIF values). These measures affirm the reliability of our analyses and the validity of our findings. Our findings are corroborated by previous studies showing maximum grip strength with fully extended elbows [25], underscoring the importance of posture in grip strength measurement. The inclusion of BMI as a predictor aligns with literature linking higher BMI to greater grip strength, highlighting the relevance of body composition in muscle strength assessments [22, 25].

The significance of these findings extends to their potential clinical and practical applications. Standardizing grip strength measurements in the sitting position with a fully extended elbow could enhance the accuracy of assessments, particularly crucial for diagnosing conditions like sarcopenia. Early and precise detection can significantly influence patient outcomes and resource allocation in medical settings [22].

Practically, these findings offer several applications. For clinicians, understanding how arm position affects grip strength facilitates more precise assessments of hand function and strength. Standardizing arm posture during measurement improves evaluation reliability and aids in tracking rehabilitation progress.

For ergonomists, the results inform the design of tools and workstations to optimize grip strength and minimize musculoskeletal injury risks in manual labor tasks.

In sports science, insights from this study can enhance grip strength training and conditioning programs. Athletes in sports requiring substantial grip strength, such as rock climbing, weightlifting, and martial arts, can benefit from tailored training protocols that consider optimal arm positions to improve grip performance and reduce injury potential.

Practical Implications

This study emphasizes the critical role of hand dominance and arm position in the assessment of grip strength. Clinicians and researchers should carefully consider these factors to ensure precise and meaningful evaluations of grip strength. For example, rehabilitation programs can benefit from customizing exercises aimed at improving grip strength, especially for the non-dominant hand and specific arm positions. Furthermore, the significant correlations observed within different arm positions underscore the importance of employing consistent measurement techniques to maintain data reliability.

Limitations

While providing insights into grip strength among young adults, this study is limited by a small, homogeneous sample, hindering generalizability across diverse populations. The cross-sectional design prevents tracking grip strength changes over time or assessing long-term effects of hand dominance and arm position on muscle development. It also overlooks confounding variables like physical activity levels, occupational demands, and hand injuries, which could influence grip strength. Moreover, reliance on self-reported dominant hand data introduces potential misclassification bias. Future research should address these limitations with larger, diverse samples, longitudinal studies, and broader variable considerations to enhance understanding of grip strength determinants across populations.

Conclusions

Our study has strong evidence endorsing standardized postures for grip strength measurements and underscores the significance of incorporating factors like age, gender, and BMI in these evaluations. We recommend adopting consistent body positions for grip strength assessments during screening and supplementary diagnosis of muscle loss in clinical and research settings. Future research should delve into how these variables interact and their implications for refining methodologies in diagnosing and managing conditions such as sarcopenia, advancing clinical practice.

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Competing interests

The authors declare no competing interests.

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ORIGINAL ARTICLE

The influence of sexual dimorphism on the manifestation of coordination abilities of volleyball players aged 15-17

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Abstract

Background and Study Aim Sexual dimorphism plays a crucial role in the design of training programs for athletes. Therefore, understanding the influence of sexual dimorphism on various abilities is essential for optimizing training regimens. The aim of this study is to determine the influence of sexual dimorphism on the manifestation of coordination abilities in young volleyball players aged 15–17.

Material and Methods Volleyball players aged 15–17 years participated in the study (n=92, training experience – 5–7 years). Fifty of them were girls, and forty-two were boys. Motor tests were used to determine the level of coordination preparedness of the volleyball players. The study assessed kinesthetic differentiation, spatial orientation, reaction, coupling, binding of movements, and balance skills. Statistical data processing was carried out using Microsoft Excel and SPSS programs.

Results For most of the compared indicators of coordination abilities, there was no significant difference between male and female volleyball players aged 15–17 ($p>0.05$). In the "Shuttle run with back forward" test, which determined the ability of volleyball players to quickly rebuild motor activity, boys outperformed girls by 5.6% ($p<0.05$). In the "Sprint test with the given rhythm", boys significantly outperformed girls by 16.6% ($p<0.001$). However, control exercises that determined the relative indicators of the above qualities did not show a significant difference. No significant differences ($p>0.05$) were found in the indicators that characterized the subjects' ability to demonstrate balance in both groups. Girls outperformed boys by 4.2% in terms of sagittal displacement of the center of mass. Comparison of the magnitude of latent periods of simple and complex visual-motor reaction by groups did not reveal significant differences among boys and girls.

Conclusions The results of the study indicate the need to implement targeted training programs to address and mitigate gender differences in coordination abilities among young volleyball players. These programs should focus on enhancing specific coordination skills. This approach ensures balanced development. Purposeful sports training can help overcome inherent physiological differences. By doing so, it leverages the benefits of tailored training to promote equality in athletic performance.

Keywords: volleyball, players, abilities, coordination, dimorphism.

Introduction

Sports training is a complex system involving various phenomena, relationships, and behaviors of its components. Achieving the goal of sports preparation is challenging. Nurturing top athletes capable of optimum performance in any conditions requires thorough knowledge of individual, age-specific, sexual, and developmental peculiarities.

In this context, creating a model of rational long-term sports preparation is essential. This model should include the application of adequate and effective training methods, appropriate training

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loads, and suitable frequency and follow-up in training cycles [1, 2, 3]. A constituent part of a sports training in volleyball is the fulfillment of various tasks which are called components of a sports preparation. Individual components are represented in sport training in various ratios depending on the period in which the athlete is situated. When the athlete is in full preparation for a competition or tournament, the preparation contains predominantly technical and tactical means. In the period of one or two months prior to the beginning of the competition period, the conditioning prevails. However, it is important not to forget about maintaining a certain level of conditioning as well as a certain level of coordination [4, 5, 6].

The level of coordination abilities in volleyball markedly underlies the quality, tempo, and stability of acquired sports skills, as well as their perfect utilization in game activities. Since the components of coordination develop mostly in the period before puberty, the crux of the development of coordination abilities falls into the period specified by the stage of elementary sport preparation. Analysis of activity in sports games shows that many athletes have shortcomings in individual technical prerequisites. Particularly in the conditions of a game, the player is often not able to master the technique optimally and utilize the experience obtained during training. One reason for this can be an insufficiently developed coordination base of an athlete. These inadequacies can be removed if a goal-oriented and systematic program for the development of coordination abilities is conducted in parallel with the skills acquisition phase. Knowing the coordination prerequisites limiting performance in sports games is essential to increase the sport preparedness of a player [7, 8, 9].

As it is known, puberty occurs on average at the ages of 13–14. It is at this time that the biological development curve rises sharply, and there is a so-called puberty jump. In some children (accelerators), the puberty jump occurs at 12–13 years, while in others (retardants), it occurs much later, at the age of 14–16 years. Therefore, the accelerators, despite having the same chronological age as the retardants, are 2–4 years ahead of the latter in the pace of biological development [10, 11].

At the age of 15, the biological development curve flattens as it accounts for post-pubertal development (completion of puberty jump). At this age, all patterns of sexual dimorphism begin to appear. Up to the age of 10, boys and girls have roughly the same rate of increase in total body size. From 11 to 12 years old, girls are ahead of boys, and at 13–15 years old, boys surpass girls in the rate of height increase. It is known that without a special training, the ability to master complex coordinated movements develops up to 15 years, and the maximum increase in strength occurs up to 16 years. In addition, the level of speed-force qualities develops up to 17 years, and the functional capacity of the body increases up to 16 years [12, 13].

The advantage of men over women in conditioning abilities (strength, speed, and endurance) is 10–20% or more. This advantage appears as early as the age of 6–10 years, weakens somewhat during puberty (12–14 years), and then increases again. Conversely, at different stages of ontogeny, women outperform men in the mobility (flexibility) of different joints by 20–30% [14, 15]. Research into the neurodynamic characteristics of athletes has shown that males have a higher speed of sensorimotor reactions based on the main characteristics of the functional mobility of nervous processes (according to the exposure of signal and time output to minimal exposure) [3, 16].

Fewer scientific studies have been conducted on the topic of sexual dimorphism in the field of coordination abilities. Most of these studies involve school-age children and students who were not systematically involved in sports. In some works, no significant differences were found in most indicators of the coordination abilities of men and women [17, 18]. The authors explain this by the relatively equal level of development of perceptual, mnemonic, intellectual, and sensorimotor processes that provide control mechanisms and regulation of complex movements. Other authors [19, 20] note that gender differences in the development of coordination abilities are noticeable as early as 6–10 years and increase after puberty.

Therefore, further observations and experiments involving qualified young athletes are required. There is a revealed contradiction between the need to determine the influence of sexual dimorphism on the manifestation of coordination abilities of young volleyball players, on the one hand, and the insufficient scientific development of methodological support for solving this pedagogical task, on the other hand. This determines the practical and scientific relevance of the study problem.

Hypothesis. It is assumed that identifying gender differences in the level of development of coordination abilities in young volleyball players aged 15–17 will allow for increased effectiveness of coordination training in particular and the training process in general.

The purpose of this study is to determine the influence of sexual dimorphism on the manifestation of the coordination abilities of young volleyball players aged 15–17.

Materials and Methods

Participants

Volleyball players aged 15–17 years participated in the study (n=92, training experience – 5–7 years). Fifty of them are girls and forty-two are boys. The adolescents and their parents were informed about all the features of the study, and the parents gave their consent to their children's participation in the experiment. The research protocol was approved by the university's ethics committee.

Research Design

Well-known motor tests were used to determine the level of coordination preparedness of volleyball players [21, 22, 23]. As part of the study, the level of kinesthetic differentiation, spatial orientation, reaction, restructuring and coordination of movements, and balance skills were determined.

Well-known motor tests were used to determine the level of coordination preparedness of volleyball players [21, 22, 23]. As part of the study, the level of kinesthetic differentiation, spatial orientation, reaction, restructuring and coordination of movements, and balance skills were determined. The following tests were used:

- Test 1: "Backwards a tennis ball throw test (points)" [21].
- Test 2: "Overstepping the gymnastic stick (s)" The stick was held by the athlete's straight arms. In the initial position, the athlete holds the stick with straightened arms. At the coach's signal, the athlete oversteps the stick 5 times with the right leg and 5 times with the left leg. The time of task fulfillment was measured in seconds [23].
- Test 3: "Numbered medicine ball run test (s)" [21].
- Test 4: "Time difference between running to the numbered balls and shuttle running (5× 3 m), s".
- Tests 5–8: Balance of volleyball players was determined using a computer stabilography. Stabilographic studies were conducted to study the quantitative criteria of static stability during the implementation of standard positions: the Mortiz-Romberg pose. The main quantitative criteria of static postures of young volleyball players were indicators: MO(x) – frontal displacement of the center of mass (CM); MO(y) – sagittal displacement of the CM; V – the average speed of movement of the CM; Koef Romb – Romberg coefficient [24]
- Test 9: "Shuttle run with back forward (3×10 m)" (s) [22].
- Test 10: Difference in time between running "Shuttle run (3×10 m)" and "Shuttle run with back forward (3×10 m)" (s).
- Tests 11–12: Subjects' abilities to feel the rhythm were assessed using the test: "Sprint test with the given rhythm" [21]. Test equipment: 11 gymnastic hoops with a diameter of 80 cm, measuring tape, stopwatch. First, the athlete runs 30 m. Then the athlete runs the distance again with 11 hoops arranged on it at maximum speed with an accuracy of 0.01 s. Result: 1) time of running 30 m; 2) time of running 30 m through the hoops; 3) difference between the time of running the 1st and 2nd distances.
- Test 13: "Movement rhythm observation" (s); Description: The player skips over the rope for 20 s in a certain tempo which they choose. The examiner counts the number of rope skips during the given period. In the second part of the test, the tested person carries out the same number of skips as in the first part. The examiner measures the time it takes to fulfill the task. Deviation from 20 s will be the criterion of success in the given test [25].
- Tests 14–16: Measuring a simple and complex visual-motor reaction. To determine the latent period of a simple and complex visual-motor reaction, the Psychodiagnostics computer program was used [26].

Statistical analysis

Statistical data processing was carried out using Microsoft Excel and SPSS programs. The following parameters were determined for each indicator: arithmetic mean ( ), standard deviation (δ), standard error (m), and significance of differences according to Student's t-test with the corresponding significance level (p). Differences were considered significant at a significance level of $p<0.05$.

Results

The obtained data (Table 1) show that there is no significant difference ($p>0.05$) between male and female volleyball players aged 15–17 for most of the compared indicators of coordination abilities, studied with the help of motor and laboratory tests. The study revealed a somewhat greater accuracy in the performance of the control exercise "Backwards a tennis ball throw test" in young male volleyball players compared to females. This difference was 7.8%, but was not statistically significant ($p>0.05$). The results of the experiment showed the advantage of the boys by 4.2% in the "Numbered medicine ball run test". However, the difference between the "Numbered medicine ball run test" and the "5×3 m shuttle run", which also showed the ability of players for spatial orientation, did not show such an advantage. No significant differences were found in the parameters that characterized the subjects' ability to maintain equilibrium in both groups ($p>0.05$). However, it is worth noting that the indicator characterizing the sagittal displacement of the center of mass was close to significant, in which female volleyball players exceeded male volleyball players by 4.2%.

In the "Running 3×10 m with the back to the direction of movement" test, which determined the ability of volleyball players to quickly rebuild movements, boys outperformed girls by 5.6% ($p<0.05$). Another indicator that characterized the

Table 1. Gender differences in the development of coordination abilities between male and female volleyball players aged 15–17 years

№	Indicator	Boys			Girls			t	p
		X̄	δ	m	X̄	δ	m		
1	"Backwards a tennis ball throw test", points	13.9	2.4	0.46	12.9	2.6	0.46	1.34	0.184
2	Overstepping the gymnastic stick (coordination of movements), s	13.1	1.3	0.23	13.4	1.5	0.29	0.67	0.501
3	Numbered medicine ball run test, (orientation), s	13.2	1.2	0.22	13.7	1.1	0.18	1.7	0.094
4	The difference in running time to the numbered balls and shuttle running 5 × 3 m (orientation), s	2.4	0.96	0.18	2.5	0.95	0.15	0.56	0.58
5	MO(x), mm	2.5	1.45	0.31	2.4	1.74	0.58	0.11	0.065
6	MO(y), mm	5.9	4.2	1.17	3.4	2.4	0.77	1.17	0.103
7	V, mm/s	10.5	2.9	0.62	9.1	1.9	0.61	1.36	0.18
8	Romberg coefficient, %	77.3	12	2.5	82.5	7.2	2.3	1.26	0.22
9	"Shuttle run with back forward (3x10 m)", s	10.7	1.1	0.2	11.3	0.7	0.13	2.5	0.015
10	The ratio of running time 3×10 m with the face and back to the direction of movement (restructuring of movements), s	2.83	0.46	0.08	2.89	0.5	0.09	0.44	0.66
11	"Sprint test with the given rhythm", s	5.59	0.38	0.07	6.52	0.35	0.08	8.3	0.001
12	Difference between 30-meters running and 30-meters running over hoops, s	0.9	0.32	0.06	1.06	0.27	0.07	1.63	0.11
13	"Movement rhythm observation", s	0.58	0.48	0.1	0.56	0.45	0.1	0.1	0.92
14	SVMR, ms	338.9	26.1	7.88	352.9	37.6	6.76	1.14	0.26
15	RCh 1-3, ms	487.4	42.9	12.9	507.3	35.1	6.01	1.55	0.13
16	RCh 2-3, ms	548.6	50.8	15.3	559.9	46.3	7.9	0.69	0.49

Note: X: Arithmetic mean; δ: Standard deviation; m: Standard error; t: Student's t-test value; p: Significance level; MO(x): Frontal displacement of the center of mass (CM); MO(y): Sagittal displacement of the CM; V: Average speed of movement of the CM; SVMR: Simple visual-motor reaction; RCh 1-3: Reaction time between signals 1 and 3; RCh 2-3: Reaction time between signals 2 and 3.

same quality and determined the difference between the "3×10 m shuttle run with the face and 3×10 m back to the direction of movement" no longer showed a significant difference between boys and girls ($p>0.05$). A similar result was obtained when testing for a significant difference in the sense of rhythm between boys and girls who systematically engage in volleyball. In the first test, "Sprint with the given rhythm," boys significantly outperformed girls by 16.6% ($p<0.001$). However, in the other two tests, which also determined the presence of a significant difference in the sense of rhythm in the two groups, this difference was not found ($p>0.05$). This is because, in these control exercises, the influence of speed qualities on the test results was eliminated.

A comparison of the latent periods of simple and complex visual-motor reactions in the two groups did not reveal any significant differences between boys and girls. Under the condition of increasing the sensorimotor complexity of the activity, young volleyball players spent less time performing the test compared to girls ($p>0.05$).

Discussion

The aim of this study was to determine the influence of sexual dimorphism on the manifestation of coordination abilities in young volleyball players aged 15–17. The results indicated that there were no significant differences between boys and girls in most of the coordination ability indicators. However, boys outperformed girls in specific tests, such as the "Running 3×10 m with the back to the direction of movement" and the "Sprint test with the given rhythm."

Scientific studies on the topic of sexual dimorphism in the field of coordination qualities have been conducted less compared to those that reflect the peculiarities of this process in the development of conditioning abilities and somatic indicators. The conducted study confirmed the data of other authors [2, 27] that sexual dimorphism in the development of coordination abilities of young volleyball players is not so clearly manifested in comparison with those who do not systematically do sports. Under the influence of training, gender features of the development of motor coordination undergo fewer changes compared to conditioning qualities [28, 29, 30]. A similar conclusion was reached by P. Hirtz [20], who conducted a study with boys and girls of the lyceum who were not systematically involved in sports. The author established a reliable advantage of boys over girls in indicators of the ability to rebuilding, coupling and binding of movements, and rhythm. However, this advantage was absent in the indicators of the ability to maintain static and dynamic balance, kinesthetic differentiation, speed of reaction, and spatial orientation.

The absence of significant differences in most of the indicators we studied can be interpreted as a relatively equal level of development of perceptual, mnemonic, intellectual, and sensorimotor processes, which provide mechanisms of control and regulation of complex movements at the central level in volleyball players. These data correspond to the results of studies by other authors [31, 32, 33].

In turn, the reliable superiority of boys over girls ($p < 0.05$) in tests for a sense of rhythm and the rebuilding of movements can be explained by the influence of speed and speed-power qualities on the test results. Supporting this interpretation, after determining the relative indicators of rhythm sensation and the rebuilding of movements in young volleyball players, which levelled the influence of the above qualities, no significant difference was found ($p > 0.05$). Other researchers hold a similar opinion [34, 35, 36]. They are convinced that if the coordination complexity of the motor task increases or the result in the "coordination" tests is associated with a significant manifestation of conditioning abilities (speed, speed-power), then the reliability of the differences in favor of male volleyball players increases compared to the data of female players.

The results of the conducted experiment showed a close to significant advantage of boys over girls in the spatial orientation test. Interesting explanations are provided by a number of authors regarding patterns of manifestations of this quality in representatives of different sexes. It is known that men demonstrate a higher level of this quality than women [10]. This assumption is partially supported by the results of another study [37]. However, a study involving athletes found no significant differences between men and women [16, 38]. For example, Sadovsky found that in taekwondo, women have an advantage in tests for accuracy of reproduction of spatial parameters of movements, as well as in maintaining balance. Along with this, the absence of gender differences was shown in studies involving representatives of other sports [39]. Still, the superiority of males who do not systematically engage in sports in spatial orientation indicators has been repeatedly noted. Ultimately, purposeful sports training reduces and even eliminates the advantages of men in this ability, due to the evolutionary and biological prerequisites of this phenomenon.

By the way, the study of the evolutionary prerequisites of coordination abilities becomes a valuable contribution to the general explanation of gender differences in those who do not play sports. A number of hypotheses have been proposed to explain the advantages of men in the manifestation of these abilities from an evolutionary perspective. According to one hypothesis, women were forced to reduce the volume of movements during the reproductive periods of their lives due to childbearing and maternal care. In turn, men continued to perform actions related to the manifestation of coordination abilities during hunting or participation in war [40]. According to another hypothesis, the responsibility of ancient men for obtaining food contributed to the development of spatial orientation abilities associated with hunting. The hypothesis about the participation of men in armed conflicts suggests that ancient people travelled long distances, participated in skirmishes with other groups, competed for food resources, and captured women. Another hypothesis suggests that successful hunters received a higher social status in ancient society and improved their spatial qualities, which in turn contributed to the achievement of such status. In any case, the evolutionary approach allows for a better understanding of the nature of spatial orientation and its importance for the coordination potential of those who systematically engage in sports and sports games, in particular.

Recent studies involving professional athletes using magnetic resonance imaging showed an increased thickness of the cerebral cortex in the area of visual-spatial control [41]. In particular, it was found that in male athletes, the processing of spatial signals is localized in the right hemisphere, while in female athletes there is no leading hemisphere. A special role in spatial orientation belongs to a specialized region of the brain – the hippocampus. Its function is to determine the location and options for moving to the next position. The hormonal status of those who systematically engage in sports also significantly affects the manifestations of spatial orientation. It is known that lower testosterone levels in men contribute to the development of spatial abilities, while in female athletes more successful spatial orientation is associated with higher testosterone levels [42].

Thus, the research results we obtained indicate the expediency of taking into account gender characteristics in the development of coordination abilities in the training process of volleyball players aged 15–17. Considering this phenomenon will contribute to the rapid and qualitative mastering of technical skills and improving the competitive activity of young athletes. Along with this, further research is needed to determine the structure of players' preparedness. By determining the value of each ability in the structure of special preparedness, it is possible to clearly plan the sample size of the load for each age period, gender, and for the individual development of children and adolescents. It is thought that it is time to pay more attention to the application of a systemic approach in implementing the individualization of the training process for young volleyball players.

Conclusions

1. The study showed no significant difference between the groups of male and female volleyball players aged 15–17 in most of the studied indicators of coordination preparedness. The only exceptions were those tests whose results were influenced by the speed capabilities of the players.
2. The lack of reliable differences in the development of coordination abilities between boys and girls who systematically play volleyball can be interpreted as a relatively equal level of development of perceptual, mnemonic, intellectual, and sensorimotor processes, which provide mechanisms of control and regulation of complex movements at the central level.
3. To explain gender differences in the development of coordination abilities, it is advisable to study the evolutionary prerequisites for the development of these abilities in representatives of both sexes. It is also necessary to analyze the results of psychophysiological studies, which explain the peculiarities of the organs and systems of the body responsible for the management and regulation of the motor activity of volleyball players.
4. The advantage of males who do not systematically play sports in the development of coordination abilities has been shown more than once. However, targeted sports training reduces and even eliminates the advantages of men in these abilities, which are determined by the evolutionary and biological prerequisites of this phenomenon.

Conflict of interests

The authors declare that there is no conflict of interests.

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ORIGINAL ARTICLE

Effects of resistance and strength training on serum phosphorus levels in male footballers: implications for physical educators and sports trainers

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Abstract

Background and Study Aim Sports performance and overall health of athletes are highly dependent on various physiological markers. Among these, blood biochemistry is of great importance and should be carefully considered in athletes' training regimens. However, the effect of strength and resistance training on serum phosphorus levels still requires further clarification and more effective solutions. The aim of this study was to determine the effect of strength and resistance training on serum phosphorus levels in elite male soccer players.

Material and Methods A sample of 90 volunteers was recruited from football athletes in the Peshawar division. Thirty participants were selected from each of the under-16, under-19, and under-23 age groups. They were divided into three groups: the Resistance Training Group (RTG), the Strength Training Group (STG), and the Control Group (CG). Each group consisted of 30 participants, with 10 from each age category. Phosphorus levels and anthropometric measurements (height, weight, BMI, waist circumference, hip circumference, and waist-to-hip ratio (WHR)) were assessed before and after a 12-week strength and resistance training intervention. Analysis of Variance (ANOVA) and paired sample t-tests were used to evaluate changes over time.

Results Significant improvements were observed in serum phosphorus levels in the Resistance Training Group (4.77±0.258 vs. 3.66±0.207, P<0.001) and in the Strength Training Group (4.31±0.304 vs. 3.66±0.209, P<0.001). A 12-week regimen of strength and resistance training significantly improved serum phosphorus levels among the participants. Analysis of variance indicated that both strength and resistance training significantly affected serum phosphorus levels after 12 weeks of intervention. Tukey's HSD test revealed that the effects of resistance training were more pronounced than those of strength training.

Conclusions This study highlights the importance of incorporating both strength and resistance training in athletic programs. These training approaches are crucial for optimizing physical health and performance. The findings underscore the need for educators and trainers to adapt and refine their methods to maximize the benefits of these interventions. By doing so, they can enhance the effectiveness of training regimens and contribute to the overall well-being of athletes.

Keywords: weight, BMI, 12-week, intervention, bone mineral content

Introduction

Resistance training (RT) and strength training (ST) are fundamental components of programs aimed at developing physical qualities. While the positive effects of RT and ST on muscle mass, strength, and power are well-documented, their impact on electrolytes, particularly serum phosphorus, in this specific population remains less explored. This gap in knowledge is particularly important when considering broader issues such as osteoporosis, a condition characterized by reduced bone mineral density (BMD) that leads to an increased risk of fractures. Osteoporosis is on the rise as the world's population ages, bringing serious emotional, physical, and financial consequences, including impairment, lower quality of life for seniors, and expensive treatment [1]. Developing countries, particularly in Asia, are experiencing a rapid increase in the occurrence of osteoporotic fractures, with Pakistan being one such example where millions are currently affected, and the numbers are projected to rise further [2]. Bone functions as a significant calcium reservoir in the body, with regulation primarily governed by endogenous hormones such as Parathyroid Hormone (PTH), and to a lesser extent, calcitriol and calcitonin [3]. The mineral composition of bones comprises approximately 80-90% calcium and phosphorus, which are essential for skeletal mineralization [4]."

Resistance training (RT) and strength training play a pivotal role in comprehensive programs for

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children and healthy adults. Their significance lies in enhancing bone strength through improvements in muscular power, nerve conduction, mineral deposition, and the maintenance of body balance [5]. Furthermore, resistance training contributes to the augmentation of musculoskeletal strength, favorable alterations in body composition, and improvements in psychological well-being, while simultaneously reducing cardiovascular risk factors [6].

To prevent osteoporosis in adulthood, it is important to maximize peak bone mass during childhood. Researchers have adopted this assumption despite the absence of conclusive proof. This suggests that the susceptibility to bone fractures and the decline in bone density associated with osteoporosis in old age can be mitigated by accumulating bone mineral content (BMC) during childhood [7]. Maximizing age-specific bone mass during growth can be particularly beneficial for preventing fractures, especially in the upper limbs. Implementing strategies to enhance and sustain bone health in the early stages of life may effectively reduce the risk of fractures and other skeletal system-related ailments [8].

Resistance training and strength training have been shown to significantly affect various blood parameters in athletes. Resistance training interventions can lead to healthier metabolite profiles, including changes in dyslipidemia biomarkers and improvements in muscle strength and size [9]. In young boys, resistance training resulted in a significant increase in serum phosphorus levels [10]. Furthermore, Clemente [11] highlighted the impact of elite soccer training on blood parameters, demonstrating changes in creatinine and other electrolytes. These findings collectively suggest that resistance and strength training can influence blood parameters, such as phosphorus concentration, indicating the potential for metabolic adaptations and improvements in athletes' physiological profiles [12]. Moreover, serum phosphorus plays a vital role in various physiological processes essential for athletic performance, including energy metabolism, muscle function, and bone health [13].

Despite the well-documented benefits of resistance and strength training on muscle strength and athletic performance, there is a paucity of research examining their effects on serum phosphorus levels in elite athletes. Phosphorus, a vital component of ATP, is integral to energy transfer and muscular contractions, both of which are critical for high-intensity sports like football [14]. Alterations in serum phosphorus levels can have significant implications for bone health, muscle function, and overall athletic performance. Previous research suggests that exercise can influence phosphorus homeostasis [15]. Studies investigating the effects of exercise on calcium metabolism have shown increased serum calcium levels following RT and ST in athletes [13]. Since phosphorus often follows a similar pattern to calcium due to their intertwined metabolic pathways [14], it is crucial to explore its specific response to RT and ST. However, limited research has specifically focused on the effects of RT and ST on serum phosphorus levels in elite male football athletes.

The effectiveness of strength and resistance training in enhancing bone mineral density and content has been demonstrated across various populations, including athletes. Therefore, it is imperative to investigate how different training regimens influence serum phosphorus levels to develop evidence-based guidelines that optimize both performance and health in elite football athletes. Additionally, this line of research could enhance the pedagogical perspectives of physical educators and sports trainers, improving their knowledge and approaches to athlete safety and performance enhancement. This study aims to fill the gap in the literature by providing a comprehensive analysis of the effects of resistance and strength training on serum phosphorus levels in elite male football athletes. Specifically, it will examine how a 12-week strength and resistance training program impacts serum phosphorus levels in the blood of these athletes.

Material and Methods

Participants

A total of 90 athletes were randomly selected from three age categories: Under-16, Under-19, and Under-23 (n=30 from each). They were divided into three groups: Resistance Training Group (RTG=30), Strength Training Group (STG=30), and Control Group (CG=30). The participants in the Resistance and Strength groups underwent a 12-week intervention, while the Control Group did not participate in any training programs. Instead, they continued with their regular daily activities. Informed written consent was obtained from all participants.

Research Design

Training Protocol. Two distinct training protocols were developed based on a comprehensive review of the relevant literature and underwent rigorous pilot testing, validation, and reliability assessments.

Strength Training Protocol The strength training protocol involved five days of training per week, including dynamic stretching and a series of strength exercises such as chest press, lateral pulldown, arm curls, squats, calf raises, back extensions, crunches, leg presses, pull-ups, leg curls, heel raises, deadlifts, and jump rows. The total duration of training increased gradually over twelve weeks.

Resistance Training Protocol. Similarly, the resistance training protocol also involved five days of training per week, with exercises such as supine bench press, leg extension, bicep curls, shrugs, triceps extension, wrist curls, 10m sprints, one-leg jumps, pop squats, burpees, medicine ball throws, and incline weighted sit-ups. The duration and intensity were gradually adjusted over the twelve-week period.

Statistical Analysis

For statistical analysis, the researcher used measures such as the mean, standard deviation, and frequency distribution. To test the hypotheses, paired t-tests, analysis of variance (ANOVA), and Tukey's HSD were employed to identify any differences in blood phosphorus levels before and after the intervention and across the groups.

Results

Table 1 shows the results of the Shapiro-Wilk test of normality for serum phosphorus concentrations before and after the intervention in three groups: the control group, the strength training group, and the resistance training group. For the resistance training group, the Shapiro-Wilk statistic is 0.942 with a significance level of 0.105 before the intervention and 0.940 with a significance level of 0.093 after the intervention. The p-values (0.105 and 0.093) are greater than 0.05, indicating that the phosphorus concentrations are normally distributed.

For the strength training group, the Shapiro-Wilk statistic is 0.936 with a significance level of 0.070 before the intervention and 0.941 with a significance level of 0.098 after the intervention. The p-values (0.070 and 0.098) are greater than 0.05, indicating that the phosphorus concentrations are normally distributed.

Similarly, for the control group, the Shapiro-Wilk statistic is 0.945 with a significance level of 0.123 before the intervention and 0.949 with a significance level of 0.160 after the intervention. The p-values (0.123 and 0.160) are greater than 0.05, indicating that the phosphorus concentrations are normally distributed.

Table 2 summarizes the pre-test and post-test mean values with standard deviations for various anthropometric measurements in the three groups: Resistance Training Group (RTG), Strength Training Group (STG), and Control Group (CG) (n=30 per group). These findings suggest that the RT program resulted in the most significant changes in body composition compared to the ST program and the control group. This is evident in the reductions observed in weight, BMI, and waist circumference for the RTG. Although all groups experienced decreases in hip circumference, the CG exhibited the greatest change. The waist-to-hip ratio remained relatively

Table 1. Shapiro-Wilk Test Results for Normality of Data of Phosphorous for all three groups

Group	Tests	Shapiro-Wilk		
		Statistic	**Df**	**Sig.**
Resistance Training Group	Pretest	0.942	30	0.105
	Post Test	0.940	30	0.093
Strength Training Group	Pretest	0.936	30	0.070
	Post Test	0.941	30	0.098
Control Group	Pretest	0.945	30	0.123
	Post Test	0.949	30	0.160

Table 2. Anthropometric measurements of Resistance Training, Strength Training and Control Group

Anthropometric measurements	Tests	RTG (n=30) Mean ± SD	STG (n=30) Mean ± SD	CG (n=30) Mean ± SD
Height	Pre Test	1.61 ± 0.033	1.60 ± 0.032	1.61 ± 0.035
	Post Test	1.62 ± 0.041	1.60 ± 0.032	1.61 ± 0.034
Weight	Pre Test	55.83 ± 4.449	55.83 ± 4.14	54.56 ± 5.84
	Post Test	54.93 ± 4.250	55.96 ± 4.48	55.47 ± 5.72
BMI	Pre Test	21.56 ± 2.06	21.77 ± 1.51	21.03 ± 2.22
	Post Test	21.21 ± 1.98	21.76 ± 1.61	21.34 ± 2.14
Waist Circumference	Pre Test	75.53 ± 2.67	75.06 ± 2.46	75.23 ± 2.42
	Post Test	74.4 ± 2.74	74.13 ± 2.60	75.92 ± 2.52
Hip Circumference	Pre Test	95.46 ± 2.66	95.26 ± 2.70	95.18 ± 2.65
	Post Test	94.23 ± 2.60	94.53 ± 2.78	95.51 ± 2.42
WHR	Pre Test	0.79 ± 0.016	0.78 ± 0.013	0.79 ± 0.014
	Post Test	0.78 ± 0.17	0.78 ± 0.016	0.79 ± 0.015

stable across all groups throughout the study.

Table 3 shows paired statistics for serum phosphorus levels in the Resistance Training group, Strength Training group, and Control group. The statistics indicated a significant difference in serum phosphorus levels during the post-intervention period for the resistance and strength training groups. The changes in phosphorus levels were significant, as shown by the increase from 3.66 mg/dl to 4.77 mg/dl (p < .000) in the resistance training group and from 3.66 mg/dl to 4.31 mg/dl (p < .000) in the strength training group. The intervention demonstrated that resistance and strength training had a significant impact on serum phosphorus levels among the athletes in both training groups.

In contrast, the control group showed minimal change in phosphorus levels (3.65 mg/dl to 3.64 mg/dl, p = .326), indicating that athletes who did not participate in any training program experienced no significant impact on serum phosphorus levels.

Table 4 presents the descriptive statistics for phosphorus levels in three groups: Resistance Training, Strength Training, and Control group. In the pre-intervention phase, both the Resistance and Strength Training groups had mean phosphorus levels of 3.660 mg/dl and 3.663 mg/dl, with standard deviations of 0.207 and 0.207, respectively. The Control Group had a slightly lower mean phosphorus level of 3.653 mg/dl with a standard deviation of 0.209. However, the analysis indicates no statistically significant difference between the groups' mean phosphorus levels (F = 0.018, p = 0.982). These findings suggest that the type of training (resistance or strength) may not have a significant impact on phosphorus levels.

Table 5 shows the descriptive statistics for serum phosphorus levels in three groups: Resistance Training, Strength Training, and Control Group. The post-intervention Resistance Training group has the highest mean serum phosphorus level (4.773 mg/dl) with a standard deviation of 0.258, followed by the Strength Training group (4.316 mg/dl) and the Control group (3.646 mg/dl) with standard deviations of 0.304 and 0.208, respectively. The analysis indicates a significant change in the mean serum phosphorus levels between the groups (F =

Table 3. Paired Samples T-test for Resistance, Strength and Control Group

Variable Name	Group	Tests	N	Mean	S.D	Df	F	Sig.
Phosphorous	Resistance Training Group	Pre test	30	3.660	.207	29	-35.521	.000
		Post test	30	4.773	.258			
Phosphorous	Strength Training Group	Pre test	30	3.663	.209	29	-11.099	.000
		Post test	30	4.316	.304			
Phosphorous	Control Group	Pre test	30	3.653	.209	29	1.000	.326
		Post test	30	3.646	.208			

Table 4. ANOVA Statistical Analysis for Serum Phosphorous (Pre-Test)

Variable Name Phosphorous Pre-Test	N	Mean	S.D	Df	F	Sig.
Resistance Training Group	30	3.660	.207	89		
Strength Training Group	30	3.663	.207		0.018	.982
Control Group	30	3.653	.209			

The mean difference is significant at the 0.05 level.

Table 5. ANOVA Statistical Analysis for Serum Phosphorous (Post-Test)

Variable Name Phosphorous Post Test	N	Mean	S.D	Df	F	Sig.
Resistance Training Group	30	4.773	.258	89		
Strength Training Group	30	4.316	.304		142.667	.000
Control Group	30	3.646	.208			

The mean difference is significant at the 0.05 level

Table 6. Tukey's HSD for Phosphorous

Dependent Variable: Phosphorous Post

Tukey HSD

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Control	Strength Training	-.67000*	.06710	.000	-.8300	-.5100
	Resistance Training	-1.12667*	.06710	.000	-1.2867	-.9667
Strength Training	Control	.67000*	.06710	.000	.5100	.8300
	Resistance Training	-.45667*	.06710	.000	-.6167	-.2967
Resistance Training	Control	1.12667*	.06710	.000	.9667	1.2867
	Strength Training	.45667*	.06710	.000	.2967	.6167

The mean difference is significant at the 0.05 level. Mean Values (Resistance Training=4.77, Strength Training=4.31, Control Group=3.64)

142.667, p = 0.000). These results suggest that both resistance and strength training have a significant effect on post-test serum phosphorus levels, with resistance training having the greatest impact.

Table 6 presents the results of a Tukey Honest Significant Difference (HSD) test conducted on the post-intervention phosphorus levels in three groups: Control, Strength Training, and Resistance Training.

Pairwise Comparisons:

1. *Control vs. Strength Training*: Mean Difference: -0.67000. The Control group has a mean phosphorus level that is 0.67 mg/dL lower than the Strength Training group. This difference is highly statistically significant with a p-value of less than 0.001.
2. *Control vs. Resistance Training*: Mean Difference: -1.12667. The Control group has significantly lower phosphorus levels compared to the Resistance Training group by 1.12667 mg/dL. This difference is highly significant (p < 0.001).
3. *Strength Training vs. Control:* This comparison is the inverse of the first, showing that the Strength Training group has higher phosphorus levels compared to the Control group by 0.67 mg/dL.
4. *Strength Training vs. Resistance Training*: Mean Difference: -0.45667. The phosphorus levels in the Strength Training group are significantly lower than those in the Resistance Training group by 0.45667 mg/dL (p < 0.001), indicating a significant difference.
5. *Resistance Training vs. Control and Strength Training*: The results show that the Resistance Training group has the highest phosphorus levels among the three groups, as indicated by the positive mean differences compared to the Control and Strength Training groups. These differences are statistically significant.

The Tukey HSD test results indicate statistically significant differences in post-intervention phosphorus levels among the Control, Strength Training, and Resistance Training groups. The Resistance Training group has the highest phosphorus levels, followed by the Strength Training group, and lastly, the Control group.

These findings suggest that physical training, especially resistance training, may lead to increased phosphorus levels. This could reflect the increased demand for phosphorus in metabolic and physiological processes associated with exercise. Elevated phosphorus levels can be important for energy production, bone health, and cellular function.

Table 7 shows the educational implications of the study on resistance and strength training on serum phosphorus levels. The research involved participants from different educational levels, specifically those enrolled in the Under-16 (8th, 9th, and 10th grades), Under-19 (9th, 10th, 11th, and 12th grades), and Under-23 (Bachelor's degree students, with four groups based on credit load: 1st Semester, 2nd & 3rd Semesters, or ADP 1st & 2nd). These diverse educational groups highlight the potential for using the study results to further age-appropriate physical education curricula.

By presenting the physiological outcomes of the structured training program, this study provides a foundation for improving teaching approaches across these educational levels. The findings could be used by physical educators, trainers, coaches, and students to develop specific training exercises that enhance physical performance and advance the science of physical education.

Table 7. Educational Implications

S.NO	Categories	Educational Level/ Class Enrolled
1	Under-16	8^{th}, 9^{th} & 10^{th} class
2	Under-19	9^{th}, 10^{th}, 11^{th} & 12^{th} class
3	Under-23	BS: 1^{st}, 2^{nd} & 3^{rd} semester/ ADP 1^{st} & 2^{nd}

From a didactic perspective, the results suggest that incorporating resistance and strength training into physical education classes can help students at various educational levels understand the need for specialized training. This approach can contribute more scientifically to the pedagogical practices of physical education and the achievement of both physical and academic learning goals. Moreover, these findings could encourage the development of teaching practices that support different educational processes within sports training settings.

Discussion

The purpose of this study was to assess the impact of resistance and strength training on serum phosphorus levels in male elite football players in Peshawar, Pakistan. The intervention outcomes indicated that the two training regimes, RT and ST, implemented over a 12-week program, enhanced mean serum phosphorus concentrations. The RTG demonstrated a higher level of increase compared to the STG, which experienced a slight increase. These findings were further supported by Analysis of Variance (ANOVA) and Tukey's HSD tests, which confirmed the superior capability of resistance training over strength training in altering serum phosphorus levels. In addition to the biochemical advancements observed with physical training, significant positive changes in anthropometric factors were also recorded, highlighting the importance of structured exercise. Accordingly, it can be asserted that both forms of training are critical not only for improving biochemical markers such as serum phosphorus but also for achieving significant anthropometric results.

Bone mineral content (BMC) is a critical factor in both bone health and overall athletic performance. Adequate BMC is necessary for maintaining strong bones, thereby reducing the risk of fractures and other sports-related injuries [4]. Monitoring serum calcium, phosphorus, and parathyroid hormone (PTH) levels is essential for assessing bone health and mineral status in athletes. Calcium and phosphorus are crucial for the formation and maintenance of bones, while the regulation of bone remodeling and turnover is controlled by parathyroid hormone (PTH) [16].

Strength and resistance training have been shown to significantly impact bone mineral content, including serum calcium and phosphorus levels. The interplay between strength training, resistance training, and bone mineral content is complex. These athletes undergo rigorous training regimens that place high demands on their musculoskeletal system, including their bones. Calcium and phosphorus homeostasis plays a crucial role in supporting bone health and adaptation to exercise-induced stress [17]. This is particularly important for male elite football athletes, who are subjected to high-intensity loads during training and competition.

Phosphorus collaborates with calcium to provide the structural framework of bones and teeth. Similarly, phosphorus levels can fluctuate during exercise, as the body utilizes more energy and metabolic functions intensify. Studies suggest that 'post-exercise serum phosphorus levels were high due to increased energy production and muscle activity during exercise' [18]. This balanced change in phosphorus is important for supporting bone health and enhancing exercise performance. The study further found that the exercise-induced rise in PTH levels is partially driven by an increase in calcium levels, highlighting the importance of physical activity in regulating PTH secretion.

Parathyroid hormone regulates calcium and phosphorus levels in the body. Additionally, clinicians sometimes advise against exercise due to the potential excretion of parathyroid hormone induced by resistance training, which can lead to a moderate increase in urinary calcium and inorganic phosphates, reducing plasma ionized calcium and phosphorus. Studies have shown that acute bouts of exercise can cause transient increases in parathyroid hormone levels, which help regulate calcium levels in the blood [19]. This hormonal response is essential for maintaining calcium homeostasis and bone health during physical activity [20].

The findings of this research support the hypothesis that there are significant differences in serum phosphorus levels among the resistance training, strength training, and control groups after the completion of the training program. These results are consistent with recent research demonstrating the impact of exercise interventions on mineral metabolism parameters [3, 8]. The observed differences in blood calcium and phosphorus levels may reflect specific adaptations induced by resistance and strength training modalities, such as alterations in bone turnover and mineral accretion [21]. Additionally, the changes in PTH levels suggest a regulatory response to exercise-induced stress, potentially involving adjustments in calcium homeostasis and parathyroid gland activity [22].

The significant differences in mineral metabolism parameters among the groups underscore the importance of tailoring exercise interventions to achieve specific physiological outcomes. Resistance training may be particularly effective for enhancing bone mineral density and calcium absorption, while strength training may exert distinct effects on phosphorus metabolism and hormonal regulation [15]. Moreover, the observed differences between the trained groups and the control group (CG) highlight the unique contributions of exercise to mineral metabolism, beyond those attributable to normal physiological variation or environmental factors.

The sample for this study was taken from educational institutions, suggesting that the findings could significantly contribute to the educational sector, particularly in the pedagogical aspects of physical education curriculum and syllabus design. This study provides deeper insights for physical educators and sports trainers, helping them improve their teaching methods both in classroom settings and on the field. Additionally, sports trainers could potentially enhance their training environment and culture, optimizing training activities to better support their athletes.

Conclusions

This study reinforces the critical role of both resistance and strength training in improving key health markers and physical attributes among elite football athletes. By implementing these findings, sports practitioners can enhance the health and performance outcomes of athletes, fostering a more scientifically informed approach to athletic training. The implications of this study could potentially improve the pedagogical approaches of physical educators, trainers, coaches, and students, facilitating the development of specific training exercises that enhance students' physical performance and advance the science of physical education.

Limitations and Recommendations

This study was not conducted as a randomized controlled trial, and therefore, we did not control or consider dietary intake, hydration status, or physical activities outside the training protocols. These factors could yield more valid results in future investigations. The study sample was taken from Peshawar, the capital of the Khyber Pakhtunkhwa (KP) province of Pakistan, so the results can only be generalized to elite footballers in different regions of KP. Additionally, the results cannot be generalized to female athletes, as they were not included in this study. Future research is encouraged to include female participants to better understand the effectiveness of both training protocols across genders.

The sample for this study was taken from educational institutions, suggesting that the findings could significantly contribute to the educational sector, particularly in the pedagogical aspects of physical education curriculum and syllabus design. This study provides deeper insights for physical educators and sports trainers, helping them improve their teaching methods both in classroom settings and on the field. Moreover, sports trainers could potentially enhance their training environment and culture, optimizing training activities to better support their athletes.

Highlights

1. Coaches, trainers, and sports scientists should prioritize resistance and strength training in conditioning programs for elite football athletes.
2. Strength and resistance training have the potential to engage a large number of students and athletes simultaneously. It is therefore recommended that comprehensive strength and resistance training programs be implemented in all educational and physical training institutions. This could contribute to improving the pedagogical approaches of physical education teachers, promoting strong and healthy bones, and reducing the risk of future bone fractures and osteoporosis.
3. Regular blood tests for calcium, phosphorus, and parathyroid hormone levels should be conducted for the diagnosis and treatment of any disorders related to bone health.
4. The same training protocols can be applied to female athletes to broaden the scope of the study.

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Conflicts of Interest

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

Validity and reliability of the physical fitness test instrument for retired martial art athletes

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Abstract

Background and Study Aim Developing exercise programs to maintain the fitness and health of retired athletes is crucial as a preventive measure against common health problems in this population. Equally important is the creation of an exercise evaluation tool to assess the effectiveness of these programs. This study aims to test the validity and reliability of a physical fitness test instrument for retired martial arts athletes.

Material and Methods This study used an evaluation approach with data collected through tests and measurements. A total of 147 subjects participated. For validity testing, there were 35 retired male martial arts athletes and 37 retired female athletes. For reliability testing, there were 36 retired male and 39 retired female martial arts athletes. The instruments used included body mass index (BMI) measurements with digital scales, flexibility measurements with the sit-and-reach test, muscle strength measurements with a leg and back dynamometer, and cardiovascular endurance measurements with the Cooper test. Validity was assessed using a concurrent validity approach. Reliability was tested using the test-retest method. The Pearson product-moment correlation was used for validity analysis, while Cronbach's alpha was used to assess reliability. The JASP software was used for the analysis.

Results For male athletes, the r-values for each test item exceeded the r-table value of 0.275, confirming the validity of the body mass index (BMI), sit-and-reach test, leg and back dynamometers, and the Cooper test. Similarly, female athletes demonstrated r-values above the r-table value of 0.267, confirming the validity of all test items. The reliability of each item was confirmed by Cronbach's alpha values, which were above the 0.7 threshold for both male and female athletes. The Cronbach's alpha value for BMI was 0.998 for both male and female athletes, indicating excellent reliability. Other test items, such as flexibility and muscle strength, also showed strong reliability, with Cronbach's alpha values ranging from 0.742 to 0.985.

Conclusions The study highlights the importance of developing valid and reliable instruments to assess the physical fitness of retired martial arts athletes. Such instruments are essential for monitoring the effectiveness of training programs aimed at maintaining the health and fitness of retired athletes. The findings of this research confirm the value of structured fitness tests. These tests effectively evaluate key physical components such as body composition, flexibility, muscle strength, and cardiovascular endurance.

Keywords: instrument validity, physical fitness, retired athletes, martial art

Introduction

Retired martial arts athletes often face a decline in physical fitness after ending their competitive careers. The sudden reduction in training intensity and structured physical activity can lead to various health problems, such as decreased cardiovascular endurance, loss of muscle strength, and reduced flexibility. Without proper intervention, these changes increase the risk of chronic conditions like obesity, cardiovascular disease, and musculoskeletal disorders. Despite the clear need for targeted fitness programs, there is a lack of validated tools to assess the specific physical fitness needs of retired athletes. This gap hinders the development of effective training and rehabilitation programs for this population.

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In this regard, a number of studies have thoroughly analyzed the issues surrounding the physical fitness of retired athletes. The experience of being an athlete should positively influence the fitness components needed in everyday life [1, 2, 3]. However, the loss of interest in exercise after retiring from sports often leads to poor physical fitness among former athletes [4]. Poor fitness can negatively affect work productivity and overall health, making it essential to maintain and improve physical fitness [5, 6]. Physical fitness refers to an individual's ability to perform daily activities with vigor and alertness, without excessive fatigue, and with sufficient energy to enjoy leisure activities and handle emergencies [7, 8]. Physical fitness is divided into two categories: health-related fitness and motor-related fitness [2, 5]. Health-related fitness includes body composition, flexibility, muscle strength and endurance, and cardiovascular endurance [9, 10, 11]. Thus, the reviewed studies demonstrate that poor physical fitness in retired athletes, stemming from a lack of post-career exercise, negatively impacts both their health and daily functioning. The decline in health-related and motor-related fitness components increases the risk of chronic diseases and impairs their ability to perform everyday tasks.

Body composition refers to the chemical makeup of the body, consisting of fat mass and fat-free mass [14, 15]. Flexibility is the ability of a person to perform a wide range of motion within the limits of a joint's movement [16, 17]. Strength is defined as the ability of muscles to resist body resistance and external load [18]. Muscular endurance refers to the ability of muscles to repeatedly contract or maintain contractions over an extended period [19]. Cardiovascular endurance is the body's capacity to sustain prolonged exercise without experiencing fatigue afterward [17, 19]. All these fitness components are influenced by factors such as age, gender, genetics, physical activity, and lifestyle [5, 13]. Fitness assessments are necessary to evaluate body condition, design appropriate exercise programs, and plan diets [12, 20]. Thus, these fitness components collectively determine an individual's overall physical health and capacity for exercise, and proper assessment of these factors helps in creating personalized fitness and health plans tailored to individual needs.

Physical fitness measurement is important as a form of screening for physical health conditions [21]. Physical fitness measurements are carried out by conducting tests and taking measurements directly using appropriate instruments for each component [12, 22]. It is crucial to tailor the measurement instruments to the characteristics of the subjects, which is why today there are many instrument developments designed for specific sports and social groups [23, 24, 25, 26]. In the process of developing these instruments, it is essential to consider the requirements of a good instrument. These requirements include objectivity, validity, reliability, ease of use, discriminatory power, and cost-effectiveness [27, 28, 29]. Each of these criteria must be met to ensure the instrument is suitable for measuring the intended fitness components [30, 31]. Consequently, proper instrument development is key to obtaining accurate and useful measurements, ensuring that assessments align with the characteristics of the subjects being measured.

Validity testing is conducted to determine the suitability between the measuring instrument and the component to be measured [32]. For instance, to measure body temperature, a thermometer is the appropriate instrument. Content validity testing is the initial stage of validity assessment during the development process. This type of validity is typically conducted by involving experts, who provide input and play a key role in instrument development [23, 24, 25]. The content validity testing process serves as an essential foundation for the subsequent stages of instrument development, such as construct validity testing and validity testing based on other factors [33, 34]. The process involves multiple rounds of testing, continuing until all experts reach consensus on the instrument's structure and design [35]. As a result, the content validity testing process ensures that each element of the instrument aligns with the component being measured. This stage highlights the necessity of ensuring the instrument's accuracy before moving on to construct validity testing and other validation phases.

Despite the existence of numerous studies on the physical fitness of retired athletes, there is still a need for further research. Many investigations highlight the decline in physical fitness components, such as muscle strength, flexibility, and cardiovascular endurance, after retirement. Furthermore, while various fitness assessment tools and programs have been developed, they often fail to address the specific needs of retired martial arts athletes. The lack of tailored, validated instruments for this group hinders the ability to design effective post-retirement fitness programs. Therefore, additional research is necessary to develop comprehensive tools that can accurately assess the physical fitness of retired athletes and support the creation of personalized interventions. This study aims to test the validity and reliability of a physical fitness test instrument for retired martial arts athletes.

Materials and Methods

Participants

The participants in this study were retired martial arts athletes who met the following criteria: they were at least 28 years old, not under medical supervision, did not have any movement limitations, were not pregnant, and were willing to participate as research subjects. A total of 147 subjects took part in the study. For the validity testing, there were 35 retired male martial arts athletes and 37 retired female martial arts athletes. For the reliability testing, 36 retired male and 39 retired female martial arts athletes were involved.

This study was conducted in accordance with established ethical guidelines for research involving human subjects. All participants provided informed consent prior to their involvement in the study. The research protocol was reviewed and approved by the institutional ethics committee to ensure the protection of participants' rights, safety, and well-being. Confidentiality of the participants' personal information was strictly maintained throughout the study, and they were informed of their right to withdraw from the study at any time without any consequences.

Research Design

A battery of tests was developed to assess key fitness components in retired martial arts athletes. The battery was created in collaboration with four experts in physical conditioning, testing and measurement, martial arts, and coaching. The experts evaluated the accuracy and relevance of each test in assessing the targeted fitness components, ensuring that the tests were appropriate for this specific athletes. They also provided input on the statistical methods used to evaluate the validity and reliability of the tests.

The tests included digital scales for body mass index (BMI), a sit-and-reach test for flexibility, a leg and back dynamometer for muscle strength, and the Cooper test for cardiovascular endurance. Testing was conducted twice with the same participants on two different days to ensure consistency in the results.

Each testing day followed a structured procedure. The measurement team prepared the necessary equipment and testing area. Participants were assigned registration numbers and completed a warm-up session. The BMI was measured first, with participants standing barefoot on digital scales, and the data was recorded. Flexibility was assessed next using the sit-and-reach test, where participants performed the test twice, with the best result being recorded.

Muscle strength was then measured using the leg and back dynamometer, with participants completing two trials, and the highest value recorded. Cardiovascular endurance was tested last, using the Cooper test, where participants ran for 12 minutes, and the distance covered was recorded. After the testing, participants completed a cool-down session independently. The same process was repeated on the second test day to ensure reliability.

Statistical Analysis

Concurrent validity was assessed using the Pearson product-moment correlation, and reliability was evaluated using the test-retest method with Cronbach's alpha. The same subjects were tested twice at different times to calculate the correlation between the two sets of results. An instrument was considered valid if the Pearson correlation coefficient (r) exceeded the r-table value, which was 0.275 for men and 0.267 for women. Reliability was determined using Cronbach's alpha, with a value above 0.7 indicating that the test was reliable. All statistical analyses were conducted using the JASP software, and a significance level of $p < 0.05$ was applied to ensure the results were statistically significant.

Results

The results are presented in the tables below. The first set of data refers to the validity results of the physical fitness test battery for retired male Pencak Silat athletes (Table 1).

Table 1. Validity test results for retired male martial arts athletes

No	Test Item	r-value	r-table	Note
1	Body mass index (BMI) (kg/m²)	0.765	0.275	Valid
2	Sit and reach (cm)	0.871	0.275	Valid
3	Leg dynamometer (kg)	0.816	0.275	Valid
4	Back dynamometer (kg)	0.779	0.275	Valid
5	Cooper test (m)	0.879	0.275	Valid

The validity test results presented in Table 1 demonstrate that all test items for retired male martial arts athletes are valid. Each r-value exceeds the corresponding r-table value of 0.275, confirming the validity of the body mass index (BMI), flexibility (sit and reach), muscle strength (leg and back dynamometer), and cardiovascular endurance (Cooper test). Specifically, the highest validity is observed in the Cooper test with an r-value of 0.879, indicating a strong correlation between the test results and the targeted component of cardiovascular endurance. Similarly, the flexibility test (sit and reach) also shows a high validity value of 0.871, demonstrating its effectiveness in measuring flexibility. The BMI test, while having the lowest r-value (0.765), still meets the validity threshold. Overall, the results indicate that all test components reliably assess the respective physical fitness aspects of retired male martial arts athletes.

The validity test results for retired female martial arts athletes are presented in Table 2. Each r-value is compared to the r-table value of 0.267, and all test items show values exceeding this threshold, confirming their validity (Table 2).

Table 2. Validity test results for retired female martial arts athletes

No	Test Item	r-value	r-table	Note
1	Body mass index (BMI) (kg/m²)	0.825	0.267	Valid
2	Sit and reach (cm)	0.791	0.267	Valid
3	Leg dynamometer (kg)	0.876	0.267	Valid
4	Back dynamometer (kg)	0.897	0.267	Valid
5	Cooper test (m)	0.795	0.267	Valid

The results in Table 2 indicate that all test items for retired female martial arts athletes are valid. Each r-value surpasses the required r-table value of 0.267, confirming the validity of the body mass index (BMI), flexibility (sit and reach), muscle strength (leg and back dynamometer), and cardiovascular endurance (Cooper test). The highest validity is observed in the back dynamometer test with an r-value of 0.897, indicating a strong correlation in measuring back muscle strength. The leg dynamometer also demonstrates strong validity with an r-value of 0.876, confirming its accuracy in assessing leg muscle strength. The BMI test shows a slightly lower, but still valid, r-value of 0.825. Overall, the results demonstrate that the tests reliably assess key fitness components for retired female martial arts athletes, with muscle strength tests showing the highest validity.

The reliability test results for retired male martial arts athletes, evaluated using Cronbach's alpha, are presented in Table 3. A Cronbach's alpha value greater than 0.7 indicates that the test is reliable, and all test items meet or exceed this threshold (Table 3).

Table 3. Reliability test results for retired male martial artists

No	Test Item	Cronbach's α	Note
1	Body mass index (BMI) (kg/m²)	0.998	Reliable
2	Sit and reach (cm)	0.751	Reliable
3	Leg dynamometer (kg)	0.974	Reliable
4	Back dynamometer (kg)	0.970	Reliable
5	Cooper test (m)	0.996	Reliable

The results in Table 3 show that all test items demonstrate strong reliability. The body mass index (BMI) test shows the highest reliability with a Cronbach's alpha value of 0.998, indicating an excellent level of consistency. The Cooper test also exhibits a high reliability score of 0.996, confirming its robustness in measuring cardiovascular endurance. Muscle strength assessments, including the leg dynamometer (0.974) and back dynamometer (0.970), also display strong reliability, showing that these tests consistently measure muscle strength. Although the sit-and-reach test for flexibility has a lower Cronbach's alpha value of 0.751, it still meets the reliability threshold, confirming that it is a consistent tool for measuring flexibility. Overall, the results demonstrate that all the test components are reliable for assessing the fitness of retired male martial artists.

The reliability test results for retired female martial artists, evaluated using Cronbach's alpha, are presented in Table 4. A Cronbach's alpha value greater than 0.7 indicates that the test is reliable, and all test items meet this criterion (Table 4).

Table 4. Reliability test results for retired female martial artists

No	Test Item	Cronbach's α	Note
1	Body mass index (BMI) (kg/m²)	0.998	Reliable
2	Sit and reach (cm)	0.742	Reliable
3	Leg dynamometer (kg)	0.985	Reliable
4	Back dynamometer (kg)	0.891	Reliable
5	Cooper test (m)	0.998	Reliable

The results in Table 4 indicate that all test items demonstrate strong reliability. The body mass index (BMI) test and the Cooper test both exhibit the highest reliability scores with Cronbach's alpha values of 0.998, reflecting excellent consistency in these measurements. The leg dynamometer also shows a high reliability score of 0.985, confirming its effectiveness in consistently assessing leg muscle strength. The back dynamometer, with a Cronbach's alpha of 0.891, also demonstrates strong reliability in measuring back muscle strength. Although the sit-and-reach test for flexibility has a lower Cronbach's alpha value of 0.742, it still meets the reliability threshold, indicating that it is a consistent tool for assessing flexibility. Overall, the results show that the tests used are reliable for measuring the physical fitness components of retired female martial artists.

Discussion

The aim of this study was to evaluate the validity and reliability of a physical fitness test battery designed specifically for retired martial arts athletes. The results of the study confirmed that all components of the test battery, including body mass index (BMI), flexibility, muscle strength, and cardiovascular endurance, demonstrated strong validity and reliability. Both retired male and female martial artists showed consistent results, with all r-values exceeding the required thresholds for validity, and Cronbach's alpha values confirming the reliability of the tests. These findings suggest that the test battery is a reliable and valid tool for assessing the physical fitness of retired martial arts athletes.

Many instruments have been developed to match the characteristics of the objects being measured [23, 26]. These developments follow key requirements like discrimination and specificity [24, 25]. As a result, researchers worldwide have created new assessment tools [22, 36, 37]. Instrument development has also been driven by new products, such as exercise programs, fitness applications, and digital scoring systems [38, 39]. Exercise programs are often designed to account for individual differences across generations [40, 41, 42]. In high-performance sports, training programs are tailored for different life stages, such as childhood, adolescence, and adulthood [43, 44, 45]. Developing exercise programs for retired athletes is an important area, given the rising prevalence of health problems in this group [42, 46, 47].

Our results show that the fitness test battery for retired martial arts athletes is valid and reliable. This is consistent with studies that emphasize the need for specific assessments. While other research has focused on tools for younger or active athletes [43, 44, 45], our study extends this by validating a tool for retired athletes. Unlike most instruments developed for active populations [38, 39], our results confirm the suitability of these tests for retired athletes. This is in line with studies that focus on the health and fitness needs of retired and older athletes [42, 46, 47].

The increased prevalence of health problems in retired athletes is linked to changes in their lifestyle and goals [5, 6]. These changes often lead to reduced physical activity, negatively affecting their fitness and overall health [4]. Additionally, many governments lack specific intervention programs for athletes in retirement, contributing to the rise in health issues [46]. This presents opportunities for researchers to develop exercise and lifestyle programs tailored to retired athletes [42]. However, the development of such programs must be accompanied by tools to evaluate their effectiveness [25, 26]. Researchers working with retired martial arts athletes have also focused on developing these instruments. The process includes defining objectives, preparing test items, and testing validity and reliability [22]. This study, in particular, centers on validating and ensuring the reliability of these tools.

Our research aligns with global trends in addressing the fitness needs of retired athletes. Like other studies focusing on specific exercise programs for athletes in retirement [42], we emphasize the importance of reliable evaluation tools. Previous research has highlighted the lack of specialized government programs for retired athletes [46]. In contrast, our study offers a validated and reliable set of instruments specifically designed for martial arts athletes. This contributes to the development of more targeted fitness assessments and interventions for this group.

The validity and reliability of test instrument items are influenced by the quality of the data generated during the measurement process [34, 36]. Measurements conducted according to established procedures will result in accurate and reliable data [48]. It is not uncommon in validity and reliability testing to encounter items that are invalid or unreliable. The causes of such issues include poor subject conditions, suboptimal performance during the test, and data entry errors [48]. Therefore, it is crucial that the measurement process follows operational standards, the specifications of the measuring instruments, and the conditions of the testing environment [30, 31].

Unlike some previous studies that encountered invalid or unreliable test items due to procedural errors or subject variability [48], our study demonstrated consistent validity and reliability across all components. This consistency may be attributed to the strict adherence to operational standards and careful subject preparation, which aligns with other research that emphasizes the importance of precise measurement protocols [30, 31]. The results confirm that our test instrument is a dependable tool for evaluating the fitness of retired martial arts athletes.

In addition to tests conducted outdoors, the accuracy of data is also influenced by natural factors, such as weather conditions [22]. Rain can disrupt or halt the measurement process. Similarly, hot weather can cause dehydration and exhaustion in test subjects [35]. To minimize the risk of data bias, many researchers prefer to conduct measurements in controlled environments, such as sports halls or multi-purpose buildings with temperature regulation. Instruments that have already been validated show high accuracy in the measurement process [25, 33, 36]. However, the competence of the data collectors also significantly impacts the results. Data collectors must be proficient in understanding operational standards, using measurement tools, and recognizing the condition of the subjects being tested [24]. There are two schools of thought regarding validity and reliability testing. One suggests that instruments that have been validated and shown to be reliable can be used without further testing. The other argues that validity and reliability are context-dependent, and re-testing is required each time the instrument is used for a new purpose [49]. Both viewpoints are well-supported, leaving researchers to decide which approach to follow.

Our study was conducted in a controlled environment, minimizing the impact of external factors like weather, similar to other studies that emphasize the importance of a stable environment for accurate measurements [22, 35]. Additionally, the high competence of our data collectors contributed to the consistency of our results, aligning with findings that stress the importance of well-trained personnel in ensuring data accuracy [24]. Unlike studies that advocate for re-testing validity and reliability, we opted for a comprehensive initial validation and reliability process, which proved effective in our context. However, we recognize the merit of re-validating tools depending on specific circumstances, as suggested in other research [49].

Our study confirms that the physical fitness test battery developed for retired martial arts athletes is both valid and reliable. The consistent results across all test items underscore the effectiveness of the instruments in measuring key fitness components such as body composition, flexibility, muscle strength, and cardiovascular endurance. However, the study has certain limitations. One limitation is the controlled environment in which the tests were conducted, which may not fully reflect real-world conditions. Additionally, the sample size, though adequate, may benefit from further expansion to include a more diverse group of retired athletes. Future research should explore the application of these fitness tests in different environments and assess the long-term impact of tailored fitness programs for retired athletes. Further studies could also focus on developing and validating instruments that are sport-specific and adaptable to various retired athlete populations.

Conclusions

The physical fitness test battery for retired martial arts athletes, which includes measurements of body composition, flexibility, muscle strength, and cardiovascular endurance, has demonstrated strong validity and reliability. Therefore, it can be concluded that all test items are consistent and compatible with the intended measurement objectives, as supported by the high validity and reliability values. Further research is needed to establish normative data for these tests to enhance their applicability across a broader population of retired athletes.

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ORIGINAL ARTICLE

The effectiveness of the physical education curriculum following the Sports Club model on the physical development of high school students in Vietnam

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Abstract

Background and Study Aim The physical development of high school students is often hindered by the limitations of traditional physical education programs, which may not fully engage students or promote balanced physical growth. In light of these concerns, the need to explore alternative educational models that can enhance students' physical development has become evident. The purpose of this article is to evaluate the potential effectiveness of a physical education curriculum following the Sports Club model in improving the physical development of high school students.

Material and Methods A total of 84 female 10th-grade students participated in the study. They were divided into two groups: an experimental group of 42 students following the Sports Club model and a control group of 42 students following the current physical education curriculum. The experiment lasted for 17 weeks. Both groups completed initial and final physical fitness tests. These tests included the 30-second sit-up test (to assess core strength), the 30-meter sprint test (to measure speed), the 4 × 10-meter shuttle run test (to evaluate agility), the standing long jump test (to measure explosive leg power), and the 5-minute running field test (to assess endurance).

Results The female students in the experimental group demonstrated greater physical development compared to the control group in all five assessment tests. The experimental group showed the most significant improvement in the 30-second sit-up test, with a growth rate of 26.71%. The lowest growth was observed in the 5-minute running field test, at 9.92%. In contrast, the control group showed its highest improvement in the 30-second sit-up test, with a growth rate of 9.44%. However, there was minimal to no improvement in the 4 × 10-meter shuttle run and the 5-minute running field test for the control group.

Conclusions The Sports Club model improved students' physical fitness more effectively compared to the current curriculum, offering greater benefits in all tested areas. It is recommended that teachers further integrate and refine the implementation of the Sports Club model in future physical education programs to enhance teaching effectiveness.

Keywords: curriculum, physical education, sports club model, physical fitness, high school students.

Introduction

Physical fitness among high school students is an important issue in many educational systems. Traditional physical education programs often do not fully engage students or promote balanced physical development. These programs can be limited in their ability to improve strength, endurance, and agility. As a result, many students show low levels of physical fitness and reduced interest in physical education. This situation highlights the need for more effective approaches. One possible solution is to explore alternative models, such as the Sports Club model, to better meet students' physical development needs.

Physical Education in schools is a vital channel for adolescents to engage in moderate to vigorous physical activity and reduce sedentary behavior [1]. Furthermore, Physical Education and school sports offer numerous benefits and can significantly contribute to the development of basic motor skills and physical fitness in children. These activities also support the development of young people in four key areas: physical, social, emotional, and cognitive [2, 3]. Previous research has demonstrated a positive correlation between higher levels of physical activity and improved academic achievement in high school students, particularly through participation in sports teams and regular physical activity [4]. Additionally, studies have shown that engaging in physical activity for at least 3 hours per week or participating in a 6-week aerobic dance program leads to measurable improvements in oxygen uptake, muscle strength, anaerobic capacity, and speed, while also contributing to fat reduction and improved body aesthetics [5, 6, 7, 8]. Physical education and sports play an essential role in

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promoting and maintaining students' health. They help children and adolescents enhance their physical fitness, learn important social norms, improve memory, develop self-discipline, and experience mental revitalization [9, 10, 11, 12, 13, 14]. Some studies have highlighted a noticeable increase in vigorous physical activity and participation in sports clubs among adolescents over the past decade, underscoring the growing importance of these activities [15,16]. Besides physical education classes, extracurricular sports club activities in high schools are considered another aspect of comprehensive education. These activities are distinct from 'core' and 'academic' extracurricular activities, which focus more on students' cognitive development rather than on the development of psychosocial and psychomotor areas [17].

Thus, increased levels of physical activity are associated with improvements in academic performance and the development of key physical attributes, such as strength, endurance, and speed. Furthermore, participation in sports contributes to the development of social skills, self-discipline, and enhanced emotional well-being.

Given the limitations of traditional physical education in fully engaging students, alternative approaches such as the Sports Club model (PCCM) have emerged as promising solutions. The Sports Club is a modern educational model, newly developed based on conventional Physical Education courses. It offers students more choices and facilitates autonomous learning, thus forming a student-centered technical education model [18]. The Sports Club is a valuable provider of sports, playing an important role in regular sports activities, especially for youth and competitive sports [19]. School Sports Clubs impact the self-esteem and social development of students participating in these clubs, helping them experience adolescence more positively and contributing to nurturing a positive character and stable emotional empathy among participating students [20, 21]. Sports Clubs have a significant effect on enhancing health, providing a new environment for improving overall well-being [22, 23, 24, 25, 26]. Middle and high school students involved in sports clubs have higher VO2 max and resting lung volumes compared to students who do not participate in sports clubs. This enhances their endurance by improving respiratory function [27]. Additionally, participation in sports club activities also fosters social learning, cultural integration, and important identity development [28]. Research shows that sports clubs in Slovenia are crucial for promoting comprehensive sports activity. Most students involved in sports clubs engage in physical activity for more than the recommended 1 hour per day and are twice as active as their peers [29]. Sports clubs, as well as physical education, are recommended to be organized to provide all young people with opportunities to learn physical activities, offering numerous chances for motor and social learning [30].

Thus, the Sports Club model presents a more flexible and student-centered approach to physical education. It promotes not only physical fitness but also social, emotional, and cognitive development. Research supports its positive impact on health, self-esteem, and social integration, making it a valuable tool for improving student well-being and participation in physical activities. Sports clubs have been shown to enhance both physical and mental development, offering students more opportunities for comprehensive growth compared to traditional physical education programs.

Building on the benefits of the Sports Club model, it is important to examine the specific impact these clubs have on students' physical fitness and overall health. Physical fitness is a collection of attributes related to health and performance, including cardiovascular endurance, muscular endurance, strength, power, body composition, flexibility, balance, agility, and reaction time [31,32]. School sports clubs significantly contribute to the development of students' physical attributes, particularly speed, strength, endurance, and motor coordination [33]. These clubs play an essential role in promoting physical activity, enhancing fitness, and reducing obesity rates among adolescents [11,34,35]. Participants in sports clubs engage in more physical activity across all age groups compared to non-participants and demonstrate higher fitness levels [36]. Participation in these clubs increases physical activity, thereby enhancing fitness and reducing the risk of obesity among elementary school students [24, 32, 37, 38]. A 2002 study indicated that the UK developed an innovative strategy linking physical education, school sports, and sports clubs. This strategy was considered groundbreaking, as it involved schools and local partners collaborating to provide comprehensive physical education and sports opportunities for students [39].

Thus, School sports clubs provide crucial benefits for students, significantly improving physical attributes and overall fitness. By encouraging greater physical activity, these clubs also help lower obesity rates. The UK's integrated strategy underscores the effectiveness of combining physical education with sports club participation for a more comprehensive approach to student health.

Given the proven benefits of sports clubs in enhancing student fitness and engagement, it is important to explore how this model is applied within specific educational systems. In Vietnam, Physical Education is a compulsory subject in the national education curriculum from grades 1 to 12. The primary goal of Physical Education is to promote health, help students choose appropriate sports for improving fitness, and develop physical skills. According to the guidelines from the Vietnamese Ministry of Education and Training, Physical Education for high school students is implemented through sports clubs. Students can select sports activities that align with their interests and the school's capabilities, aiming to further develop health and hygiene skills, enhance awareness and athletic talents, and assist students with athletic abilities in choosing suitable career paths [40]. However, currently, high schools in Vietnam have not yet implemented the curriculum reform for physical education as outlined. Most schools still follow the old curriculum (not using the sports club model). This has significantly impacted students' learning needs, leading to a lack of interest in physical education and insufficient development of students' physical fitness. To address this issue, a new teaching curriculum has been developed using the sports club model for physical education in high schools, which is the reason for conducting this study.

Materials and Methods

Participants

The participants in this study were 84 healthy female 10th-grade students enrolled in high school Physical Education classes. None of the participants had any physical health issues, and none smoked, consumed alcohol, or were taking any medications. The students were divided into two groups: an experimental group and a control group (Table 1).

The experimental group consisted of 42 female students, participating in the Sports Club model (PCCM) with specific involvement as follows: 10 students in football, 10 in volleyball, 11 in basketball, and 11 in badminton. The control group also consisted of 42 female students, who followed the standard 10th-grade Physical Education curriculum currently applied in their high school.

All participants were informed about the testing procedures and provided written consent prior to the study. This research was approved by the Councils of the High School for use with the students.

Table 1. Subject features (n=84)

Group	Age (years old)	Height (cm)	Weight (kg)
Experimental (n=42)	15.32 ± 0.52	159.90 ± 4.78	53.68 ± 4.13
Control (n=42)	15.76 ± 0.61	160.02 ± 4.96	54.12 ± 4.68

Procedure

Before the start of the semester, all participating students completed a brief questionnaire regarding their personal information and history of sports-related injuries. Participants with any issues would have been excluded from the study, but no students were disqualified based on the results. Next, all students in both the experimental and control groups underwent an initial physical fitness test (the first test) before the Physical Education curriculum began. These tests were conducted in accordance with Decision 53/2008/QĐ-BGDDT, dated September 18, 2008, issued by the Ministry of Education and Training, which provides regulations for assessing and grading students' physical fitness by age and gender, ensuring high reliability [41]. Five physical fitness tests were selected to assess the students' fitness: the 30-second sit-up test (to evaluate core strength), the 30-meter sprint test (for speed), the 4 × 10-meter shuttle run test (for agility), the standing long jump test (to measure explosive leg power), and the 5-minute running field test (to assess endurance). These tests are appropriate for evaluating physical fitness according to the high school Physical Education curriculum [42, 43]. Afterward, students in both groups participated in a 17-week Physical Education curriculum (equivalent to one semester) under the same conditions, including class time, use of facilities, weather, and climate. At the end of the semester, both groups underwent a second physical fitness test (post-experiment) using the same five tests as in the initial assessment.

The Physical Education curriculum follows the Sports Club model (PCCM)

The Sports Club model (PCCM) lasts for 17 weeks (equivalent to one semester), with one session per week, each session lasting 90 minutes. It covers five components: General Theory, Basic Techniques, Games, Physical Fitness, and Competitions (Table 2). The selected content is fundamental, popular, and suitable for the students' age, gender, health, physical fitness, and regional characteristics. It is designed to align with the school's facilities and the teachers' capabilities. The curriculum aims to develop physical qualities such as speed, strength, endurance, coordination, and flexibility. PCCM includes sports such as football, volleyball, basketball, and badminton. Students can choose their preferred sport for training. The training method emphasizes active student engagement, with a balanced combination of group training and individual practice to ensure adequate physical activity. Various games and competitions are incorporated to make the training attractive and engaging for students. The curriculum also encourages students to manage, self-direct, and participate in peer evaluations. In contrast, the current Physical Education curriculum for 10th-grade students (control group) consists of two sessions per week, each lasting 45 minutes. This curriculum focuses on a single sport, without allowing students to choose their preferred activity.

Table 2. The Physical Education Curriculum following the Sports Club model (PCCM)

Weeks	Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Test
General theory																			
Football		x	x	x															
Volleyball		x	x	x															
Basketball		x	x	x															
Badminton		x	x	x															
Basic Techniques																			
Football		x	x	x	x	x	x	x	x	x	x	x							
Volleyball		x	x	x	x	x	x	x	x	x	x	x							
Basketball		x	x	x	x	x	x	x	x	x	x	x							
Badminton		x	x	x	x	x	x	x	x	x	x	x							
Games and Physical Fitness																			
Speed					x		x		x		x		x						
Strength						x		x		x		x							
Endurance						x		x		x		x		x	x	x	x	x	
Coordination					x		x		x		x		x	x	x	x	x	x	
Flexibility						x		x		x		x		x					
Competition																			
Football													x	x	x	x	x	x	
Volleyball													x	x	x	x	x	x	
Basketball													x	x	x	x	x	x	
Badminton													x	x	x	x	x	x	

The main focus is on the techniques of that specific sport, which are used to assess students' end-of-term grades.

Statistical Analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) for Windows, version 20. An independent samples t-test was used to evaluate the differences in each physical fitness test between the experimental and control groups. A paired samples t-test was applied to determine the differences between pre-test and post-test results within each group. The significance level was set at $p < 0.05$.

Results

To establish a basis for evaluating the physical development of students, a pre-experiment physical fitness test was conducted for both the experimental and control groups to allow for comparison. The results are presented in Table 3. Table 3 shows the mean differences in physical fitness between the control and experimental groups of 10th-grade female students before the implementation of the Sports Club model (PCCM). There were no significant differences in any of the physical fitness tests (standing long jump, 30-meter sprint, 30-second sit-up test, 4 × 10-meter shuttle run, 5-minute running field) between the two groups, with $p > 0.05$. This indicates that the fitness levels of the two groups were comparable. Thus, the implementation of the 17-week Physical Education curriculum could proceed for each specific group.

At the end of the Physical Education curriculum (semester end), the study reassessed physical fitness to compare the mean differences between the experimental and control groups post-experiment. The same five tests were used as in the initial assessment. The results of the independent samples t-test for these comparisons are presented in Table 4.

Table 4 shows a significant difference in physical fitness between the control and experimental groups of 10th-grade female students after the 17-week Physical Education curriculum. Post-experiment, the average values in all five physical fitness tests - explosive leg strength (standing long jump test), speed (30-meter sprint test), core strength (30-second sit-up test), agility (4 × 10-meter shuttle run test), and endurance (5-minute running field test)—were significantly higher in the experimental group compared to the control group, with $p < 0.001$. These results indicate that the Sports Club model (PCCM) had a positive impact on all five

Table 3. The results of the independent samples t-test for the physical fitness of experimental and control groups before the experiment

Test	Groups	N	M ± SD	t-Value	p-Value
Standing long jump (cm)	Experimental	42	148.40 ± 7.19	-0.291	.772
	Control	42	148.83 ± 7.73		
30-m sprint (s)	Experimental	42	7.09 ± 0.44	0.216	.830
	Control	42	7.07 ± 0.45		
30-s sit-up test (times)	Experimental	42	12.98 ± 1.66	0.924	.361
	Control	42	12.57 ± 1.74		
4 × 10-m shuttle run (s)	Experimental	42	13.16 ± 0.40	0.157	.876
	Control	42	13.15 ± 0.38		
5-min running field (m)	Experimental	42	796.90 ± 21.15	-0.539	.593
	Control	42	799.76 ± 27.12		

Note: M: Mean; SD: Standard deviation

Table 4. The results of the independent samples t-test for the physical fitness of experimental and control groups after the experiment

Test	Groups	N	M ± SD	t-Value	p-Value
Standing long jump (cm)	Experimental	42	172.98± 8.04	11.360	.000
	Control	42	153.00 ± 7.61		
30-m sprint (s)	Experimental	42	6.24 ± 0.33	-11.384	.000
	Control	42	6.87 ± 0.15		
30-s sit-up test (times)	Experimental	42	17.71 ± 2.48	7.517	.000
	Control	42	13.88 ± 1.55		
4 × 10-m shuttle run (s)	Experimental	42	11.97 ± 0.97	-7.226	.000
	Control	42	13.10 ± 0.22		
5-min running field (m)	Experimental	42	884.64 ± 20.91	19.783	.000
	Control	42	802.26 ± 18.09		

Note: M: Mean; SD: Standard deviation

physical fitness qualities, contributing to balanced, harmonious, and comprehensive development in the students.

The comparison of physical fitness results for the experimental and control groups before and after the 17-week Physical Education curriculum, using the paired samples t-test, is presented in Table 5.

Table 5 shows the differences in physical fitness results for female 10th-grade students before and after the 17-week Physical Education curriculum in both the control and experimental groups. In the experimental group, there was a significant difference between pre-test and post-test results across all physical fitness tests, with $p < 0.001$. The growth rates in physical fitness were particularly high, with the largest increase observed in the 30-second sit-up test (26.71%). This was followed by the standing long jump test (14.21%), the 30-meter sprint test (13.62%), the 4 × 10-meter shuttle run test (9.94%), and the 5-minute running field test, which had the lowest growth rate at 9.92%. In the control group, there were also differences between pre-test and post-test results, but only three tests showed significant changes: the standing long jump test (explosive leg strength), the 30-meter sprint test (speed), and the 30-second sit-up test (core strength), all with $p < 0.05$. The remaining two tests, the 4 × 10-meter shuttle run test (agility) and the 5-minute running field test (endurance), did not show significant differences ($p > 0.05$). Although the control group also experienced improvements in physical fitness after the experiment, the extent of improvement was relatively low. The highest increase in the control group was observed in the

Table 5. The results of the paired samples t-test of experimental and control groups before and after the experiment

Test	Pre – test (M ± SD)	Post – test (M ± SD)	t-Value	p-Value	Percentage of change (%)
Groups Experimental					
Standing long jump (cm)	148.40 ± 7.191	172.98 ± 8.04	-16.798	.000	14.21
30-m sprint (s)	7.09 ± 0.44	6.24 ± 0.33	9.907	.000	13.62
30-s sit-up test (times)	12.98 ± 1.66	17.71 ± 2.48	-11.465	.000	26.71
4 × 10-m shuttle run (s)	13.16 ± 0.40	11.97 ± 0.97	7.848	.000	9.94
5-min running field (m)	796.90 ± 21.15	884.64 ± 20.91	-19.934	.000	9.92
Groups Control					
Standing long jump (cm)	148.83 ± 7.73	153.00 ± 7.61	-3.193	.003	2.73
30-m sprint (s)	7.07± 0.45	6.87 ± 0.15	2.726	.009	2.91
30-s sit-up test (times)	12.57 ± 1.74	13.88± 1.54	6.440	.000	9.44
4 × 10-m shuttle run (s)	13.15± 0.38	13.10 ± 0.22	0.767	.448	0.38
5-min running field (m)	799.76 ± 27.12	802.26 ± 18.09	-0.491	.626	0.31

Note: M: Mean; SD: Standard deviation

30-second sit-up test (9.44%). Other tests showed minimal improvements, such as the 30-meter sprint test (2.91%) and the standing long jump test (2.73%), while the 4 × 10-meter shuttle run test and the 5-minute running field test showed negligible increases of 0.38% and 0.31%, respectively.

This means that both curricula impact the physical fitness of female 10th-grade students. However, the newly developed Sports Club model (PCCM) shows higher effectiveness, as evidenced by greater growth in physical fitness (Figure 1), with a more consistent impact across all five tests. In contrast, the current Physical Education curriculum also affects the physical fitness of female 10th-grade students but does so unevenly across the five tests, resulting in lower overall effectiveness and less improvement in physical fitness.

Discussion

The purpose of this article is to evaluate the potential effectiveness of a physical education curriculum following the Sports Club model (PCCM) in improving the physical development of high school students. The research results demonstrate that PCCM has a positive impact on the physical fitness of female high school students in Vietnam. After 17 weeks of implementing PCCM, the average values in all five physical fitness tests for the experimental group were significantly better than those of the control group, with $p < 0.001$ (independent samples t-test). The paired samples t-test also showed significant differences between pre-test and post-test results in all physical fitness tests for the experimental group, with $p < 0.001$. The growth rates were notably high across all five physical fitness tests, with the highest increase in the 30-second sit-up test (core strength) at 26.71%. This was followed by the 30-meter sprint test (speed) at 13.62%, the 4 × 10-meter shuttle run test (agility) at 9.94%, the standing long jump test (explosive leg power) at 14.21%, and the lowest increase in the 5-minute running field test (endurance) at 9.92%.

The control group, which followed the current Physical Education curriculum, also showed differences in physical fitness between the pre-test and post-test after 17 weeks. However, only three tests showed significant improvements: the standing long jump test (explosive leg strength), the 30-meter sprint test (speed), and the 30-second sit-up test (core strength), with $p < 0.05$. The other two tests, the 4 × 10-meter shuttle run test (agility) and the 5-minute running field test (endurance), did not show significant differences, with $p > 0.05$. The growth rates in physical fitness for the control group were very low. The highest increase was 9.44% in the 30-second sit-up test, while the lowest was 0.31% in the 5-minute running field test. The other tests showed increases of less than 3%. The new PCCM curriculum, which includes four sports: football, volleyball, badminton, and basketball, offers a more diverse training experience. It significantly enhances students' physical fitness. In contrast, the current curriculum focuses on only one sport and places less emphasis on physical fitness training. This results in lower overall effectiveness.

Our findings align with several intervention studies that have shown that participation in sports clubs leads to improved physical fitness. This improvement is particularly notable in endurance and strength, as evidenced in Tahira's research [11]. Participation in sports clubs is also associated with higher physical fitness in terms of endurance, strength, power, and agility, as highlighted in the research by Drenowatz and colleagues [35]. Some previous studies share similar views with our research. They demonstrate a positive relationship between sports participation and the physical development of students [6, 36, 37, 44].

A study by Golle et al. [38] indicated that physical development is positively influenced by both the living environment and participation in sports clubs. Specifically, children living in urban areas and those participating in sports clubs were found to be healthier and showed faster physical development compared to children living in rural areas. This was evident in measures of endurance (9-minute run), upper body strength (1 kg ball lift), and lower body strength (triple jump test). The authors recommend that sports club programs, offering engaging activities, could be an effective means to enhance physical fitness in children living in rural areas [38].

A study in Vietnam also assessed the effectiveness of a 15-week basketball training curriculum following the Sports Club model (BPCM) for female students at Saigon University [45]. The research team used five physical fitness tests, as outlined by the Ministry of Education and Training [41], consistent with those used in our study. The results indicate that the 15-week BPCM training curriculum led to higher scores in speed (30-meter sprint test), agility (4 × 10-meter shuttle run test), and maximal aerobic capacity (5-minute running field test) compared to the current program. However, there were no significant differences in core strength (30-second sit-up test) and explosive leg power (standing long jump test) between the BPCM program and the current curriculum [45]. This suggests that the BPCM program did not have a comprehensive impact on the overall physical fitness of the participants. The potential reasons for this could include differences in the characteristics of the study subjects or a lack of diversity in the sports activities included in the program.

In a previous study, we assessed the effectiveness of cooperative teaching in Physical Education on the physical development of high school students [42]. In that study, we also used five physical fitness tests, as outlined by the Ministry of Education and Training [41]. The results indicated that the innovative teaching method (cooperative learning) had a positive impact on all five physical fitness tests: the 30-second sit-up test, 30-meter sprint test, 4 × 10-meter shuttle run test, standing long jump test, and 5-minute running field test. Students in the experimental group showed higher growth rates in physical fitness compared to the control group. These findings are consistent with our current research, likely due to the shared focus on innovating Physical Education teaching in secondary schools and the similar target group of high school students.

A study by Vicente-Rodriguez G and colleagues demonstrated that students who participated in football training within a sports club experienced increased bone mass, reduced fat mass, and increased lean body mass. Additionally, they achieved better results in physical fitness tests, including the 30-meter sprint, 300-meter run (anaerobic capacity), and 20-meter shuttle run (maximum aerobic power) [46]. These results align with our study in terms of physical fitness development in areas such as speed, agility, and endurance. However, core strength and explosive leg power have not yet been evaluated.

Basterfield et al. [32] also demonstrated that participation in sports clubs is positively associated with body mass index (BMI) and particularly benefits physical fitness development. This was evident through several tests, including the 20-meter shuttle run test (20mSRT), handgrip strength (Handgrip), standing broad jump (Broad Jump), and sit-and-reach [32]. These results are similar to our research in terms of physical fitness assessments, such as agility and explosive leg power. However, their study did not fully evaluate speed, core strength, and endurance.

Brettschneider demonstrated the impact of sports club activities on the physical development of youth in Germany [33]. These results align with our study in showing the positive impact of sports club activities on strength (standing broad jump) and endurance (6-minute run test). However, their study did not fully assess other aspects of physical fitness, such as speed, core strength, and explosive leg power. The lack of comprehensive evaluation may be attributed to differences in the research subjects.

Additionally, other studies have shown that participation in sports clubs is beneficial for various health behaviors, such as reduced screen time, healthier eating habits, and decreased substance abuse. Participation in sports clubs is often considered a key factor for a healthier lifestyle during childhood and adolescence, beyond the impact on body weight alone [47, 48]. Furthermore, there is evidence that the psychological and social benefits of participating in sports exceed those of other forms of physical recreation. Specifically, engaging in sports is associated with better emotional regulation, higher self-esteem, increased confidence, and greater competence. It also correlates with improved social skills and fewer symptoms of depression [20, 49]. In practice, it is argued that participation in sports clubs, especially team sports, is a crucial component of children's social development due to interactions with coaches and peers [50, 51]. However, these aspects of overall health were not considered in our study.

Our study highlights the benefits of innovating the Sports Club model (PCCM) in developing physical fitness among high school students, particularly female students in Vietnam. Students participating in PCCM demonstrated better physical fitness across all five tests. Therefore, we recommend enhancing the implementation of the Sports Club model in high schools in Vietnam and tailoring programs to students' levels to achieve optimal results.

However, it is important to acknowledge some limitations of the study. First, the sample was limited to female students, which may restrict the generalizability of the findings to the broader student population, including male students. Second, the study focused on a specific set of physical fitness tests, which may not fully capture other important dimensions of physical development, such as flexibility or balance. Additionally, factors such as the students' socioeconomic background, prior physical activity experience, and motivation were not controlled, which could have influenced the results.

Future research should aim to include a more diverse sample of students and explore a wider range of physical fitness metrics. Longitudinal studies would also be valuable to assess the long-term effects of PCCM on students' physical and mental well-being. Furthermore, investigating the impact of different sports and training intensities within the PCCM framework could help optimize the curriculum for various student needs.

Conclusions

This study underscores the significance of innovating physical education through the Sports Club model (PCCM) to improve physical fitness among high school students, particularly female students in Vietnam. The PCCM approach offers a more diverse and engaging training experience, allowing students to participate in multiple sports and benefit from a well-rounded physical education program. The adoption of this model can contribute to better physical development and overall well-being, addressing the limitations of traditional physical education programs.

The Sports Club model promotes active student participation, fosters autonomy, and encourages peer interaction, creating a more dynamic learning environment. Implementing PCCM more widely in schools can lead to more effective outcomes, ensuring that physical education is better aligned with students' needs and interests. By continuing to develop and refine such innovative approaches, schools can significantly enhance the physical fitness and engagement of their students.

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ORIGINAL ARTICLE

Physiological adaptations in small-side games combined with speed-endurance training: analyzing heart rate and rate of perceived exertion

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Abstract

Background and Study Aim Monitoring physiological responses during training is crucial for understanding how athletes adapt to various exercise intensities. However, the specific effects of combining Small-Sided Game (SSG) and Speed-Endurance Training (SET) on these parameters require the search for more effective solutions. This study aims to determine the effect of combined SSG and SET on heart rate (HR) and rate of perceived exertion (RPE).

Material and Methods This quantitative research employed an experimental method with a weekly pretest-posttest design. The study population consisted of eighty-two members of the Unesa Soccer Student Activity Unit. A sample of eighteen individuals was selected through simple random sampling. The sample had the following characteristics: age 20±0.69 years, weight 65±9.54 kg, height 165.22±4.31 cm, and BMI 22.82±1.92. Data were collected using the Polar H-10 device, and RPE interviews were conducted ten minutes after each training session. Data analysis was performed using paired sample t-tests and Wilcoxon tests.

Results The results showed a significant difference in HR for pair 1 ($p = 0.037$), but no significant differences for pair 2 ($p = 0.058$) or pair 3 ($p = 0.076$). However, the results for RPE indicated significant differences in pair 1 ($p = 0.001$), pair 2 ($p = 0.004$), and pair 3 ($p = 0.002$). The combination of SSG and SET led to an increase in HR during the first and second weeks. In the third week, HR decreased. RPE increased from the first to the second week. It then stabilized in the third and fourth weeks, indicating a consistent level of effort. The decrease in HR during the third week, despite the same effort level, suggests that the athletes successfully adapted to the training program.

Conclusions The combination of SSG and SET demonstrates potential as an effective training method for improving both physiological performance and adaptation in athletes. These findings offer valuable insights into how athletes respond to structured training programs, providing a foundation for future research and practical applications in sports training. The results contribute to a deeper understanding of the role that specific training combinations play in athlete development and recovery.

Keywords: small-sided game, speed-endurance training, heart rate, rate of perceived exertion, physiological response.

Introduction

Optimal athletic performance relies on athletes' ability to adapt to varying training intensities. Therefore, monitoring physiological responses is key to evaluating these adaptations. Developing training strategies that enhance athletes' physical adaptation and overall performance is of great importance in this context. This is particularly relevant to football, where performance depends on physical fitness, psychological factors, technical skills, and team tactics [1, 2]. The development of modern soccer requires players to possess optimal physical and technical abilities. Soccer is characterized by high-intensity activities, such as sprinting, rapid changes of direction, and jumping, necessitating training that mirrors the competitive physical demands of the game [3]. Modern soccer matches also involve more passing, ball dribbling, and crossing, reflecting a significant increase in match intensity [4, 5]. Therefore, soccer players require a high level of fitness to meet the physical demands of the game.

To prepare players for optimal performance during matches and reduce the risk of injury, training loads are often recorded and monitored [6, 7, 8]. By monitoring heart rate data during matches, coaches can more accurately adjust training programs for individual players, supporting their physical development and readiness. This approach ensures that training loads and recovery are optimally

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managed, leading to the best possible results [9, 10].

According to previous research, training monitoring involves the systematic collection of data reflecting the volume, intensity, and content of training, serving as an effective tool for controlling training [11]. This aligns with findings that training monitoring is essential for minimizing injury risk, assessing fatigue and recovery needs, and preventing negative training adaptations [12]. In addition to monitoring physical development, measuring training load and recording training outcomes are crucial. It is vital to assess the physical demands placed on each player, such as distance covered, acceleration, and physiological responses like heart rate or rate of perceived exertion. Therefore, systematic and accurate monitoring is necessary to support the physical development of soccer players.

During the competition preparation phase, gradual increases in training load have been shown to reduce injury risk and maintain or even enhance performance throughout the season [8, 13, 14, 15]. However, training loads are often not systematically recorded or monitored, leading to discrepancies between the prescribed loads and each player's physical capacity in the program design. In addition to focusing on physical, technical, and tactical improvements, coaches must also design training programs that meet the team's needs within a relatively short timeframe. To address this challenge, an innovative approach is proposed by combining two different training models, Small-Sided Games (SSG) [16] and Speed-Endurance Training (SET) [17], to analyze the effectiveness of this combination in soccer team training.

Another study showed that SSG, which involve playing in small groups on a smaller field, have become a focus of research aimed at improving technical skills and physical performance across various sports [16]. At a basic level, this training method allows players to enhance their technical and tactical skills in smaller game situations, improve player interactions, and accelerate decision-making [18, 19]. Meanwhile, SET is defined as high-intensity interval training that leads to maximum oxygen uptake (VO2 Max) [17, 20].

Other studies focus on the development of training models that combine SSG with HIIT methods, which have recently gained increasing use in professional soccer clubs [21, 22]. The combination of these two training models, which enhance physical, technical, and tactical abilities, has a positive impact on team development. Both HIIT and SSG offer similar benefits for soccer-specific performance variables and endurance, with minimal impact on neuromuscular performance [3].

In this context, SSG have been introduced as a specific alternative to running-based high-intensity interval training, providing simultaneous improvements in technical skills, tactical abilities, and overall fitness levels in soccer players [21, 23]. Despite the positive effects of this combined training approach, previous studies have mainly focused on monitoring and recording physical abilities, with limited attention given to how physiological responses, such as heart rate (HR) and rate of perceived exertion (RPE), are influenced during such training. Therefore, it is crucial to investigate the impact of combining SSG and SET on HR and RPE responses. This study hypothesizes that the combination of SSG and SET will significantly enhance soccer players' physiological responses, particularly HR and RPE, over a four-week training period.

Materials and Methods

Participants

The study was conducted with 18 active soccer players from the Student Soccer Unit of Universitas Negeri Surabaya, selected from a population of 82 using random sampling. The participants had an average age of 20±0.69 years, an average weight of 65±9.54 kg, an average height of 165.22±4.31 cm, and a BMI of 22.82±1.92.

Research Design

An experimental method with a pretest-posttest design was used. The research was conducted over four weeks, with three sessions per week. The design of the study is presented in Figure 1.

Figure 1 shows that in the first week of the study, a baseline test was conducted at the end of the week to gather initial data from the participants. After

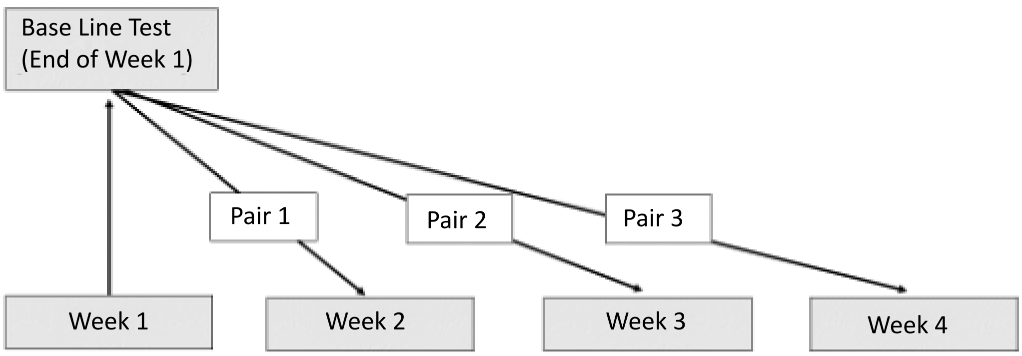

Figure 1. Research Design

collecting the baseline data, participants underwent the treatment during the following weeks. In the second week, the first t-test was conducted to compare baseline results with the outcomes from the second week's treatment. This test aimed to assess changes occurring after two weeks of treatment. In the third week, the second t-test was conducted to compare baseline results with the outcomes from the third week's treatment, aiming to identify changes occurring after three weeks. In the fourth week, the third t-test was conducted to compare baseline results with the outcomes from the fourth week's treatment, evaluating changes occurring after four weeks. The data included the percentage of heart rate per minute (BPM) for the sample during the combination of SSG and SET, as well as RPE for each week of training. Data collection instruments included a heart rate monitor and interviews. The Polar H10 heart rate monitor was used to measure the players' heart rates during training sessions. Additionally, interviews were conducted to obtain players' subjective views on their effort during training, using an RPE scale of 1-10.

Training Program

The training program design is illustrated in Figure 2, which demonstrates the combination of SSG with SET, including player positioning, sprinting distances, and repetition patterns.

The combination of SSG with SET begins with the Blue and Red players positioned in Area 2 (Figure 2a), then they sprint 20 meters through Area 3 towards Area 1 (Figure 2b). In Area 1, they play for 18 seconds, with the Blue players tasked with attacking and the Red players defending. Afterward, they return to Area 2 by sprinting 20 meters (Figure 2c) and play again for 18 seconds, this time switching roles—Red players attack, and Blue players defend (Figure 2d). Next, the players sprint 20 meters back to SSG 1 and repeat the game pattern. Each repetition involves a total of 4 sprints, with each sprint covering 20 meters, so the total sprint distance per repetition is 80 meters, and the total SSG playtime is 72 seconds (18 seconds x 4). During one training session, the players perform 8 repetitions, which means the total sprint distance covered is 640 meters (80 meters x 8 repetitions), and the total SSG playtime is 576 seconds (72 seconds x 8 repetitions). The interval between activities is 1:2, ensuring a balance between work intensity and rest. The training involved three groups alternating between SSG and SET. When one group was engaged in SSG with SET, the other two groups performed recovery by passing the ball outside the training area. During recovery, players remained active by passing the ball to each other on the sidelines to keep their heart rate within the training zone. This approach not only improves physical fitness but also maintains high training intensity and ensures positive player adaptation.

Statistical Analysis

The means and standard deviations of the data in this study are presented. Tests for normality were conducted as part of the prerequisites. The Shapiro-Wilk test was used to assess whether the data followed a normal distribution. Paired sample t-tests and Wilcoxon tests were employed to analyze the differences between the pretest and posttest results. Statistical significance was set at $p<0.05$.

Results

Table 1 presents the descriptive statistics for HR from 18 subjects over four weeks. In Week 1 (baseline), the average HR was 88.56 with a standard deviation of 5.19. In Week 2, the average HR increased to 90.22 with a standard deviation of 4.07. In Week 3, the average HR was 89.78 with a standard deviation of 5.26, and in Week 4, the average HR was 89.72 with a standard deviation of 5.38.

Table 2 presents the descriptive statistics for RPE from 18 subjects over four weeks. In Week 1 (baseline), RPE values ranged from 8.00 to 9.00, with an average of 8.06 and a standard deviation of 0.24. In Week 2, RPE values ranged from 9.00 to 10.00, with an average of 9.06 and a standard deviation of 0.24. In Week 3, RPE values ranged from 8.00 to 10.00, with an average of 8.61 and a standard deviation of 0.61. Finally, in Week 4, RPE values ranged from 8.00 to 9.00, with an average of 8.61 and a standard deviation of 0.50. The RPE data indicates that the average perceived effort of the

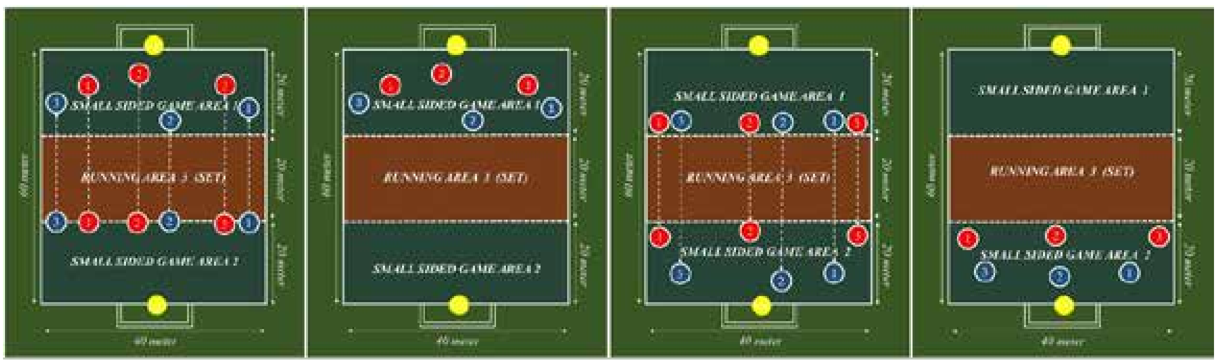

Figure 2. Training Program

subjects slightly increased from Week 1 to Week 2, then stabilized in Weeks 3 and 4.

Based on Table 3, the normality test results show that the heart rate (HR) percentages for Weeks 1-4 have a significance value (sig > 0.05), indicating that the data are normally distributed. Therefore, a paired sample t-test was conducted. Conversely, the normality test results for RPE for Weeks 1-4 show a significance value (sig < 0.05), indicating that the data are not normally distributed. Consequently, the Wilcoxon test was conducted.

Given that the HR data showed a normal distribution, the paired t-test was used, while the Wilcoxon test was applied for the non-normally distributed RPE data (Table 4).

According to Table 4, the results of the paired samples t-test show a significance level (sig. 2-tailed) of 0.037 for Pair 1, 0.058 for Pair 2, and 0.076 for Pair 3. With a significance threshold of 5% (0.05), among the three HR comparisons, only HR in Pair 1 is significant (0.037 < 0.05), while HR in Pair 2 (0.058 > 0.05) and HR in Pair 3 (0.076 > 0.05) are not significant.

According to Table 5, the results of the non-parametric Wilcoxon test show a significance level (sig. 2-tailed) of 0.000 (<0.05) for Pair 1, 0.004 (<0.05) for Pair 2, and 0.002 (<0.05) for Pair 3. With a significance threshold of 0.05, the results indicate that all pairs are statistically significant.

Table 1. Descriptive Statistics for Average HR

Week	N	Minimum	Maximum	Mean	Std. Deviation
Week 1 (baseline)	18	81.00	97.00	88.56	5.19
Week 2	18	83.00	96.00	90.22	4.07
Week 3	18	80.00	98.00	89.78	5.26
Week 4	18	79.00	98.00	89.72	5.38
Valid N (listwise)	18				

Note: Data are presented as mean±SD.

Table 2. Descriptive Statistics for RPE

Week	N	Minimum	Maximum	Mean	Std. Deviation
Week 1 (baseline)	18	8.00	9.00	8.06	0.24
Week 2	18	9.00	10.00	9.06	0.24
Week 3	18	8.00	10.00	8.61	0.61
Week 4	18	8.00	9.00	8.61	0.50
Valid N (listwise)	18				

Note: Data are presented as mean±SD.

Table 3. Normality Test Results for HR.

Week		Shapiro-Wilk		
		Statistic	Df	Sig.
HR Result	HR Week 1	.942	18	.318
	HR Week 2	.940	18	.288
	HR Week 3	.942	18	.311
	HR Week 4	.945	18	.350
RPE Result	RPE Week 1	.253	18	.000
	RPE Week 2	.253	18	.000
	RPE Week 3	.741	18	.000
	RPE Week 4	.624	18	.000

Table 4. Results of Paired Samples T-Test

Pair	T	df	Significance (2-tailed)
Pair 1: HR Baseline - HR Week 2	-2.263	17	.037*
Pair 2: HR Baseline - HR Week 3	-2.028	17	.058
Pair 3: HR Baseline - HR Week 4	-1.891	17	.076

Note: Percentage of change between pre- and post-training performance. *Significant difference, p < 0.05.

Table 5. Results of Wilcoxon Test

Pair	Z	Significance (2-tailed)
Pair 1: RPE Baseline – RPE Week 2	-4.243[b]	.000*
Pair 2: RPE Baseline – RPE Week 3	-2.887[b]	.004*
Pair 3: RPE Baseline – RPE Week 4	-3.162[b]	.002*

Note: [b]- Based on negative ranks; Percentage of change between pre- and post-training performance. *Significant difference, $p < 0.05$.

Discussion

The objective of this study was to evaluate the effect of combining SSG and SET on physiological responses, specifically HR and RPE. The results reveal an interesting pattern in physiological responses and perceived exertion over the 4-week training period. In the first week, the increase in maximal HR in zones 4 and 5 during training indicates that the workload was sufficiently high, triggering an increase in heart rate as the body responded to meet oxygen demands. The continued increase in HR during the second week suggests that the body was still in the adaptation phase to the given training load. In the third week, although HR remained higher than in the first week, the increase was not significant, indicating that the players' bodies had begun to physiologically adapt to the training intensity. The decrease in average HR in the fourth week may reflect improved heart efficiency in pumping blood, a positive sign of adaptation from the training. This finding aligns with previous research [11], which also showed that during the first and second weeks, the average HR Max (maximum heart rate) of players was in high training zones 4 and 5, indicating very high work intensity during training.

This indicates that the players were in optimal condition to improve their cardiovascular fitness and aerobic capacity. On the other hand, the RPE increased from the first week to the second week, reflecting that the players perceived a higher intensity and training load, which is expected during the initial adaptation phase to a new training program. In the third and fourth weeks, RPE remained stable, indicating that the players exerted relatively the same effort from week 1 to week 4.

The results of the study demonstrate that the combination of two training models, SSG and SET, positively influences players' physiological capabilities. These findings align with previous research [3, 24], which showed that combining these two training models is effective in consistently maintaining high work intensity throughout the training period, a key factor for fitness development and performance optimization in soccer. In the context of our research, the combined training of SSG and SET aims to create a holistic approach to soccer player development. By integrating technical, tactical, speed, and endurance elements, this training provides a balanced physiological impact while developing competitive soccer skills. Players undergoing this combined training are expected to perform optimally in matches and better manage both physical and mental challenges.

The combination of SSG and SET training has a wide-ranging physiological effect on soccer players. SSG incorporates technical and tactical drills that enhance players' coordination and creativity in small-sided scenarios, while SET emphasizes the development of speed and endurance. This integrated approach improves both aerobic and anaerobic capacity in players [25].

In the context of our research, the combination of SSG and SET simultaneously involves both aerobic and anaerobic activities. SSG training can increase players' aerobic capacity through continuous play, while SET training improves anaerobic endurance through short sprints and speed training. Heart rate optimization and cardiovascular system improvement occur through the integration of these two methods, which comprehensively stimulate the cardiovascular system. High-intensity SSG increases heart rate and blood flow, while SET enhances the cardiovascular system's ability to efficiently deliver oxygen and nutrients to muscles. Maximum speed and sprinting ability are also developed through SET training, and when combined with SSG, this approach helps players simultaneously enhance their maximum speed and sprinting ability. Short sprints in SET build muscle strength that supports speed, while SSG game situations improve players' reactions and sharpness in dynamic game conditions. High-speed endurance development also occurs when the combination of SSG and SET allows players to experience game situations that test their endurance at high speeds, providing significant benefits when they need to maintain intensity and performance quality during high-pressure matches.

This study demonstrates that the combination of SSG and SET positively affects soccer players' physiological responses, specifically HR and RPE. These findings are consistent with previous research, which has shown that this training combination increases overall training intensity, as reflected by elevated HR and higher RPE ratings [3, 11, 16]. The results of this study have important practical implications for designing training programs for soccer players. Combining SSG with SET can be an effective strategy to improve players' physical conditioning and endurance, which can enhance their performance in actual matches. This study confirms that the combination of SSG and SET is a holistic soccer training model that has a positive impact on players.

One limitation of this study is the relatively small sample size of 18 participants, which may limit the generalizability of the findings to a broader population of soccer players. Additionally, the study was conducted over a four-week period, which is a relatively short timeframe for assessing the long-term effects of training. Future research could focus on a longer training cycle and a larger sample size to provide more accurate conclusions.

Conclusions

The combination of Small-Sided Games (SSG) and Speed-Endurance Training (SET) represents a comprehensive training approach that integrates both physiological and tactical development in soccer players. This approach has the potential to enhance players' overall fitness, technical abilities, and adaptability to high-intensity match conditions. By addressing both aerobic and anaerobic demands, this combined training model can be effectively incorporated into soccer training programs to improve long-term performance.

Future research could explore the effects of extended training periods beyond four weeks to determine long-term adaptations and performance improvements. Additionally, investigating the application of this training approach across different age groups, skill levels, and competitive environments could provide valuable insights into its versatility. Further studies may also focus on optimizing the balance between SSG and SET for specific training objectives, such as injury prevention or recovery strategies.

Conflict of interest

The authors have not received any support or endorsement from any organization for the submitted work.

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ORIGINAL ARTICLE

Effect of high intensity in every set on strength gains in novice lifters: a randomized controlled trial

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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 program design is essential for maximizing adaptation by balancing strength gains, minimizing stress, and enhancing recovery. However, it remains unclear whether training at high intensity in every set is necessary for optimal strength gains. This study compares the effects of two distinct 6-week resistance training programs on maximum strength in novice lifters.

Material and Methods Twenty participants were recruited and randomly assigned to either the traditional strength program (TSP) or the combined strength program (CSP), both periodized to increase the number of sets every 2 weeks over a total of 6 weeks. A two-way ANOVA was used to analyze maximum isometric strength, maximum dynamic strength, and strength ratio differences between groups and over time.

Results The results showed significant increases in maximum isometric knee extension and elbow flexion strength for both the TSP (CI 95% = 55.87-99.92 N and CI 95% = 10.93-26.86 N, respectively) and the CSP (CI 95% = 43.32-111.42 N and CI 95% = 8.54-28.96 N, respectively). Similarly, maximum dynamic knee extension and elbow flexion strength also improved significantly in both programs (knee extension: TSP CI 95% = 8.16-17.24 kg and CSP CI 95% = 9.10-28.32 kg; elbow flexion: TSP CI 95% = 6.74-11.26 kg and CSP CI 95% = 3.05-10.70 kg). Additionally, strength ratios increased significantly in both the TSP (knee extension CI 95% = 0.87-1.36 N/kg and elbow flexion CI 95% = 0.15-0.42 N/kg) and the CSP (knee extension CI 95% = 0.68-1.59 N/kg and elbow flexion CI 95% = 0.14-0.39 N/kg) from baseline.

Conclusions Both training programs led to significant increases in maximum strength metrics. Novice practitioners did not need to train at high intensity in every set to achieve substantial strength gains. This was particularly evident during the early weeks of training, when recovery and adaptation are critical.

Keywords: isometric strength, dynamic strength, strength ratio, knee extension, preacher curl

Introduction

From the resistance training literature, it is well-documented that high-intensity resistance training is beneficial for increasing muscle strength among practitioners. According to guidelines from the American College of Sports Medicine, an intensity of approximately 70% or more of one-repetition maximum (1RM) is generally recommended for practitioners aiming to achieve significant strength gains [1]. This guideline is well-supported by a substantial body of evidence from previous studies, which consistently demonstrate that training at this intensity is effective in enhancing maximum strength [2, 3, 4].

Mechanistically, high-intensity resistance training facilitates a range of physiological adaptations that contribute to improvements in muscle strength. For instance, such training promotes increased maximal motor unit recruitment, referring to the activation of a greater number of motor units within a muscle [5]. This increased recruitment is crucial for generating higher force levels by enhancing the utilization of fast-twitch muscle fibers, which are primarily responsible for maximum strength and explosive power [6]. Additionally, improvements in motor unit synchronization and firing rate — both of which refer to the efficiency and frequency at which motor units are activated — play a significant role in increasing muscle strength [7]. Furthermore, muscle hypertrophy, or the increase in muscle size, is another important factor contributing to greater muscle strength [8]. This phenomenon is commonly observed in response to high-intensity training, as the mechanical tension placed on muscles leads to structural adaptations [9]. From a practical perspective, these findings suggest that training at or above 70% 1RM is particularly well-suited for individuals seeking to maximize their strength gains, as it triggers the necessary physiological adaptations to achieve this goal.

However, consistently training at high intensity presents challenges, as it can lead to the accumulation of stress on musculotendinous units and contribute to fatigue due to the high levels of perceived effort required. To mitigate these issues,

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alternative techniques, such as low-intensity resistance training with blood flow restriction (BFR), have been suggested as beneficial, as they allow for reduced external load during training [10]. This approach may facilitate faster recovery by causing less muscle damage [11] and reducing fatigue while still promoting substantial strength gains [12].

However, a recent meta-analysis demonstrated that while low-intensity resistance training with BFR significantly increases muscle strength, its strength gains remain suboptimal compared to traditional high-intensity resistance training [13]. For example, in one study, participants experienced a 31.2% increase in 1RM knee extension following traditional high-intensity training at 80% 1RM, compared to only a 19.1% increase from low-intensity BFR training at 20% 1RM [14]. Numerous studies further support the superiority of high-intensity resistance training for muscle strength gains [15, 16, 17].

From a practical perspective, an optimal resistance training program should not only maximize strength gains but also minimize stress and enhance recovery. While recent meta-analyses suggest that lifting light loads with BFR alone may be less effective for strength gains, it could still offer recovery benefits. Novice lifters, in particular, may benefit from a combined approach that reduces the need for consistently high-intensity training, allowing for easier recovery without compromising progress. It remains unclear whether combining high-intensity training with low-intensity BFR can produce strength gains comparable to high-intensity training alone, especially when the total number of sets is controlled. Therefore, this study aims to compare the effects of two different 6-week resistance training programs on maximum strength in novice lifters.

Materials and Methods

Participants

Before implementing the exercise intervention, this study used a priori power analysis. The analysis employed G*Power version 3.1.9.7 software with the following parameters: Effect size = 0.75, α = 0.05, and Power = 0.80, considering a 20% dropout rate. The total number of participants was set at 20. These input parameters were based on a previous study, which used a similar experimental design to investigate muscle strength changes in two groups [18].

Twenty healthy young males (age = 21.1±0.4 years, height = 1.74±0.5 m, weight = 69.1± 11 kg) were recruited for this study. All participants met specific inclusion criteria. They were under 22 years of age, had no resistance training experience, and had no functional limitations that could affect training. Additionally, none had a history of using pharmacological substances, ergogenic drugs, performance supplements, or anabolic steroids that could influence muscle strength. A thorough health screening was conducted by a physician, and informed consent was obtained from all participants. To prevent bias, participants were randomly assigned to either traditional strength program (TSP) (n=10) or combined strength program (CSP) (n=10).

Research Design

This study aimed to compare changes in maximum strength metrics influenced by two different resistance training programs. An experimental design was used, comparing two groups with standardized controls for training volume, exercise order, execution pattern, repetition tempo, and rest intervals. Eligibility criteria required participants to have no prior structured resistance training experience to minimize bias related to experience. All resistance training sessions were supervised by a specialist in a controlled laboratory environment.

Baseline assessments included measurements of maximum voluntary isometric strength using an isokinetic dynamometer (ISOFORCE, Germany). Maximum dynamic strength was assessed via 1RM knee extension and 1RM preacher curl, using standard training machines (Body-solid, USA). The study was conducted in accordance with the Declaration of Helsinki, and informed consent was obtained from all participants. Ethical approval was granted by the institutional review board of Burapha University (Reference No. G-HS046/2566(C1)).

Resistance training programs

In the traditional strength program (TSP), participants engaged in one training session per week, held on Monday, throughout the 6-week program. This duration was selected based on a classic study indicating that substantial strength adaptations, especially in novice lifters, could occur relatively quickly within this time frame [19]. Participants performed 3 sets of knee extensions on a machine (Body-Solid, USA) and 3 sets of preacher curls on a machine (Body-Solid, USA) during the first two weeks. The training intensity was set at 70% 1RM for every set. Repetitions were executed to failure in both exercises to ensure maximal motor unit recruitment.

Each repetition followed a fixed tempo of 2 seconds for both the concentric and eccentric phases, with a 60-second rest interval between sets. Participants were instructed to maintain a full range of motion throughout each repetition, and each set was terminated upon concentric failure. A 4-minute rest interval was given between exercises, with knee extensors being trained first. By the third and fourth weeks, the set volume was doubled to six sets for both exercises. In the fifth and sixth weeks, the volume increased to eight sets per exercise.

In the combined strength program (CSP),

participants also trained one session per week. During the first two weeks, they performed two sets at high intensity (70% 1RM) and one set at low intensity (30% 1RM) with BFR for both knee extension and preacher curl exercises. The BFR was achieved using elastic wraps (Grizzly Fitness, Canada) fastened proximally on the upper arms and legs. The elastic wraps were approximately 7.5 cm wide and 120 cm long.

To standardize the BFR protocol, a clinical pneumatic cuff (H+CUFF, USA) was applied to the upper legs and arms. The pressure was gradually increased until a vascular Doppler could no longer detect blood flow, confirming complete occlusion. The pressure was then reduced to 40% of the occlusion pressure, allowing participants to acclimate through alternating periods of pressure on and off. Participants were subsequently provided with elastic wraps and instructed to apply them at a perceived pressure similar to 40% of the occlusion pressure.

As highlighted by a previous study, individuals can be trained to sense the target BFR pressure through repeated inflations and deflations at 40% arterial occlusion pressure, resulting in improved accuracy in estimating the target pressure [20]. The high-intensity sets were performed first, followed by the low-intensity sets. The elastic wrap was tightened only before the low-intensity sets began. After finishing each BFR set, the wraps were released immediately. The total duration of blood flow restriction was kept under 10 minutes, as recommended by a previous study [21].

In the third and fourth weeks, the training volume increased to three sets of each intensity. By the fifth and sixth weeks, participants performed four sets of each intensity for both exercises. All other training variables remained consistent across both groups. A summary of the training programs is provided in Table 1.

Maximum isometric strength test

For maximal isometric strength testing, participants completed a standardized warm-up, followed by a 3-minute rest. Testing began with the isometric knee extension strength assessment, conducted on a seated bench with secure fixation using strap belts. Participants sat upright on the bench with approximately 90 degrees of hip flexion and about 60 degrees of knee flexion (full knee extension = 0 degrees). This knee angle was chosen based on a previous study, which reported that participants could generate the most force at this angle compared to shorter or longer angles [22].

Participants were instructed to exert maximal force against an immovable resistance pad as hard and fast as possible for three 5-second repetitions, with a 15-second rest interval between attempts. After the knee extension test, participants were given a 1-hour rest to allow for fatigue recovery. Elbow flexion strength testing followed a similar protocol. Participants lay supine, with strap belts securing their torso on the bench, and their elbows fixed at a 90-degree angle. This angle was selected based on a study that identified it as the strongest elbow flexion angle during isometric testing [23].

Participants performed maximal elbow flexion for three 5-second repetitions, with a 15-second rest between attempts. Accurate measurements were

Table 1. Training programs

Week	Traditional strength program	Combined strength program
Week 1-2	a. Knee extension 3 sets 70% 1RM b. Preacher curl 3 sets 70% 1RM	a. Knee extension 2 sets 70% 1RM b. Knee extension 1 sets 30% 1RM + BFR c. Preacher curl 2 sets 70% 1RM d. Preacher curl 1 sets 30% 1RM + BFR
Week 3-4	a. Knee extension 6 sets 70% 1RM b. Preacher curl 6 sets 70% 1RM	a. Knee extension 3 sets 70% 1RM b. Knee extension 3 sets 30% 1RM + BFR c. Preacher curl 3 sets 70% 1RM d. Preacher curl 3 sets 30% 1RM + BFR
Week 5-6	a. Knee extension 8 sets 70% 1RM b. Preacher curl 8 sets 70% 1RM	a. Knee extension 4 sets 70% 1RM b. Knee extension 4 sets 30% 1RM + BFR c. Preacher curl 4 sets 70% 1RM d. Preacher curl 4 sets 30% 1RM + BFR

Note. Equipment - Knee extension machine (Body-Solid, USA); Preacher curl machine (Body-Solid, USA); Number of repetitions - To failure; Tempo (Concentric: Eccentric phase) - 2seconds each; Range of motion - Full range of motion; Rest interval between sets - 60 seconds; Rest interval between exercises - 4 minutes; Exercise order: a>b or a>b>c>d; Abbreviation: TSP - Traditional strength program; CSP - Combined strength program; BFR - Blood flow restriction; 1RM - 1 repetition maximum.

ensured using a gold-standard isokinetic machine (ISOFORCE, Germany).

Strength ratio calculation

The strength ratios for both knee extension and elbow flexion were calculated by dividing the maximum isometric strength for each movement by the participant's bodyweight, following the method used in a previous study [24]. This ratio provided a normalized measure of strength relative to body mass, allowing for more accurate comparisons across participants of varying sizes.

Maximum dynamic strength test

Maximum dynamic strength was assessed using knee extension and preacher curl machines (Body-Solid, USA) by determining the heaviest load a participant could lift for one repetition with a full range of motion. After a standardized warm-up consisting of 3 sets of 10 repetitions with progressively heavier, self-selected loads for each exercise, participants began the one-repetition maximum (1RM) attempts. These attempts started with a load heavy enough to allow for 3-5 repetitions, and the weight was gradually increased until the participant failed to lift the load for one perfect repetition. Each attempt consisted of one repetition, with at least 3 minutes of passive recovery between attempts. Participants were strongly encouraged to exert maximum effort during each trial. The 1RM for knee extension was tested first, followed by the 1RM for the preacher curl after a one-hour rest.

Statistical Analysis

The statistical analysis was conducted to investigate the effects of two different training protocols on muscle strength and perceived effort. The Shapiro-Wilk test was used to assess the distribution of the data. Descriptive statistics were calculated to summarize the baseline characteristics of both groups. A one-way ANOVA was employed to compare baseline variables between the two groups. Levene's test was used to assess the homogeneity of variances. A two-way repeated measures ANOVA was conducted to compare the effects between groups (TSP vs. CSP) and time points (Pre vs. Post). Changes in each muscle strength metric and 95% Confidence Intervals (CI95%) were also calculated. Effect size was calculated using the formula: mean change / pooled SD, with interpretation based on Hopkins' recommendations: 0.00–0.19: Trivial; 0.20–0.59: Small; 0.60–1.19: Moderate; 1.20–1.99: Large; ≥2.00: Very large [25]. Statistical analyses were performed using IBM SPSS Statistics version 20, with the significance level set at $\alpha = 0.05$.

Results

The baseline characteristics of the participants are shown in Table 2. Of the 20 participants, 2 dropped out, 1 due to loss of interest and 1 due to an unexpected injury, resulting in 8 participants in the CSP group and 10 in the TSP group. Statistical analysis revealed no significant differences in participant characteristics between the two groups at baseline ($p > 0.05$).

The changes in muscle strength from pre- to post-intervention are presented in Table 3. Both the traditional strength program (TSP) and the combined strength program (CSP) groups showed significant improvements in all measured parameters ($p < 0.05$). The effect sizes (ES) indicate strong improvements across most measures for both groups.

Significant main effects of time were observed for all strength metrics (all $p < 0.01$). Firstly, substantial increases in isometric knee extension strength were recorded, with Δ32.3% (ES = Large) in the CSP group and Δ34% (ES = Large) in the TSP group. Similarly, significant increases in isometric elbow flexion strength were observed, with Δ38.5% (ES = Large) in the CSP group and Δ43.1% (ES = Large) in the TSP group (Figure 1).

Moreover, 1RM strength significantly increased in both the TSP and CSP groups. In knee extension, the increases were Δ19.7% (ES = Moderate) for TSP and Δ26.8% (ES = Moderate) for CSP. For elbow flexion, the increases were Δ28.6% (ES = Moderate) for TSP and Δ17.8% (ES = Small) for CSP (Figure 2).

Similarly, both knee extension and elbow flexion strength ratios significantly increased in both groups. For TSP, the increases were Δ32.7% (ES = Large) for knee extension and Δ44.6% (ES = Large) for elbow flexion. For CSP, the increases were Δ31.7% (ES = Moderate) for knee extension and Δ40% (ES = Large) for elbow flexion (Figure 3).

However, no significant main effects of group or interaction were observed for any strength metrics (all $p > 0.05$) (Table 3).

Table 2. Participants characteristics at baseline

Variable	Traditional strength program (n=10)	Combined strength program (n=8)	F	p-value
Age (years)	21.25±0.7	21±0	1.27	0.28
Height (cm)	173.1±5.5	174.6±5.3	0.01	0.93
Body mass (kg)	68.5±11.4	69.5±11.9	0.48	0.50

Note. Data were presented as mean ± standard deviation

Table 3. Changes in muscle strength from Pre to Post

Measurement	Traditional strength program (n=10)				Combined strength program (n=8)				Effect p		
	Pre	Post	Change (CI95%)	ES	Pre	Post	Change (CI95%)	ES	Group	Time	Interaction
Isometric KE (N)	229.10 ±57.51	307.00 ±67.65 *	77.90 (55.87;99.92)	1.24	239.88 ±62.91	317.25 ±59.40 *	77.37 (43.32;111.42)	1.26	.71	.00	.98
Isometric EF (N)	43.90 ±12.54	62.80 ±5.47 *	18.90 (10.93;26.86)	1.95	48.63 ±10.29	67.37 ±13.24 *	18.75 (8.54;28.96)	1.64	.29	.00	.98
1RM KE (kg)	64.41 ±9.02	77.11 ±13.01 *	12.70 (8.16;17.24)	1.13	69.74 ±18.13	88.45 ±27.00 *	18.71 (9.10;28.32)	0.81	.31	.00	.18
1RM EF (kg)	31.50 ±11.07	40.50 ±9.85 *	9.00 (6.74;11.26)	0.86	38.75 ±13.82	45.63 ±13.21 *	6.88 (3.05;10.70)	0.51	.28	.00	.26
KE strength ratio (N/kg)	3.39 ±0.90	4.50 ±0.93 *	1.11 (0.87;1.36)	1.22	3.57 ±1.02	4.70 ±1.00 *	1.13 (0.68;1.59)	1.12	.68	.00	.93
EF strength ratio (N/kg)	0.65 ±0.21	0.94 ±0.17 *	0.28 (0.15;0.42)	1.49	0.73 ±0.21	1.00 ±0.17 *	0.27 (0.14;0.39)	1.42	.40	.00	.87

Note. Data were presented as mean ± standard deviation. 1RM - 1 repetition maximum; KE - Knee extension; EF - Elbow flexion; ES - effect size. * - $p < 0.05$

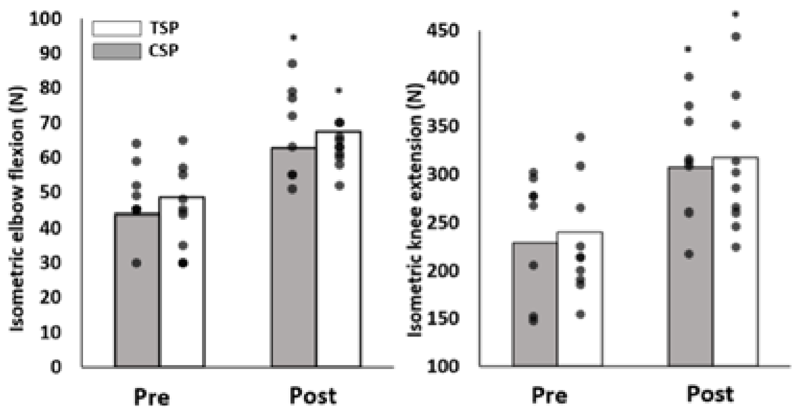

Figure 1. Change in isometric elbow flexion and isometric knee extension from Pre to Post. Individual analyses were illustrated in black dots. * - indicates $p < 0.05$ to Pre.

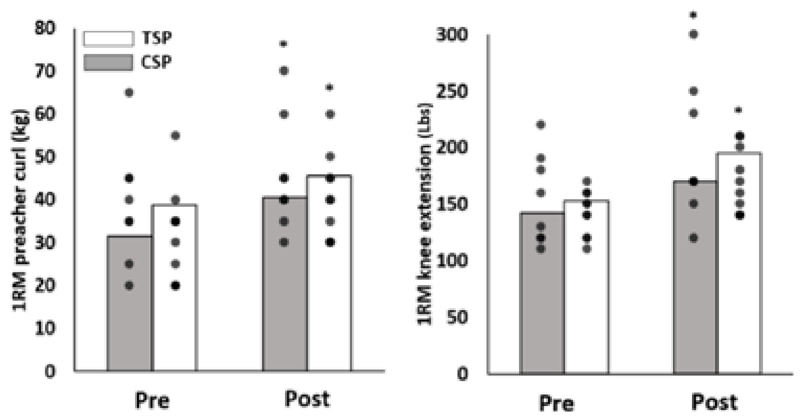

Figure 2. Change in 1RM preacher curl and 1RM knee extension from Pre to Post. Individual analyses were illustrated in black dots. * - indicates $p < 0.05$ to Pre.

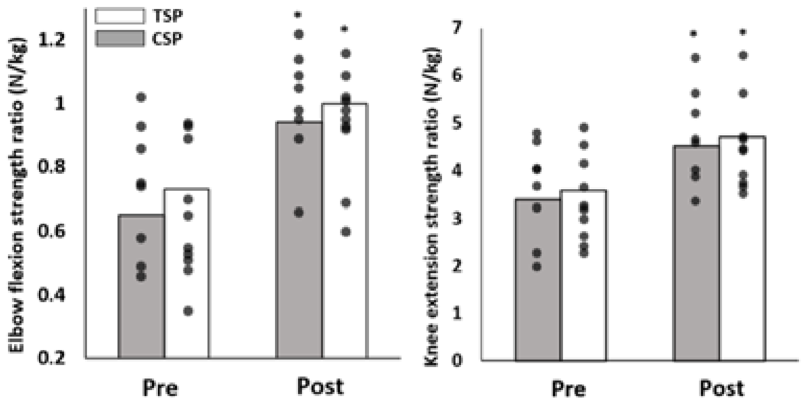

Figure 3. Change in elbow flexion strength ratio and knee extension strength ratio from Pre to Post. Individual analyses were illustrated in black dots. * - indicates p < 0.05 to Pre

Discussion

This study compared the effects of two different 6-week resistance training programs, CSP and TSP, on maximum strength gains. The primary findings revealed that CSP resulted in strength gains comparable to those achieved with TSP across all strength metrics. To the author's knowledge, this is the first study to demonstrate that achieving maximum strength gains does not necessarily require maintaining high intensity across every set throughout the entire training program, especially for novice lifters during the early weeks of training. These findings have significant implications for the design of training programs. The substantial improvements in all strength metrics were likely attributable to neural adaptations occurring in the early stages [19]. It was hypothesized that these neural adaptations played a crucial role in the observed strength gains, particularly in novice lifters. To better understand these neural adaptations, future studies could benefit from using electromyography (EMG) or electroencephalography (EEG) to investigate the underlying neural mechanisms associated with this program.

In comparison, our findings are consistent with several previous studies that demonstrated high-intensity resistance training alone can significantly increase maximal strength. For instance, Clark and colleagues found that knee extension training at 80% 1RM increased 1RM knee extension by 13% in 4 weeks [26]. Similarly, another study reported a 16.8% increase in isometric knee extension strength after 12 weeks of training at 80% 1RM [27]. Additionally, Libardi and colleagues observed a 38.1% increase in 1RM leg press following 70-80% 1RM resistance training [28]. Our study extends this literature by showing that after 6 weeks of high-intensity training, both maximum isometric and dynamic strength, as well as strength ratios, improved in both upper and lower body musculature.

Moreover, in the combined group (CSP), participants performed high-intensity sets for only half of their training volume, with the remaining half consisting of low-intensity sets with BFR. This innovative approach demonstrated that novice lifters did not need to use high-intensity sets throughout their entire training program. Previous research supports this strategy, showing that low-intensity resistance training with BFR can minimize muscle damage [11] and enhance recovery [12]. This aligns with Scott's suggestion that incorporating low-intensity training with BFR might help manage musculotendinous stress, promoting recovery and allowing for more frequent training sessions [10]. Our study's findings reinforce this idea, suggesting that integrating high-intensity sets only part of the time can be effective for novice lifters. To further explore this approach, future research should examine the impact of increasing training frequency within this combined training regimen to determine if more frequent application could yield additional benefits.

Additionally, we addressed the limitations of BFR training on muscle strength, as reported in earlier meta-analyses. It was found that while low-intensity resistance training with BFR can increase muscle strength to some extent, the gains are still inferior to those achieved with high-intensity resistance training alone [13]. For instance, Martin-Hernandez and colleagues showed that low-intensity 20% 1RM knee extension training with BFR increased 1RM knee extension and isokinetic knee extension by 6.3-7% and 2.6-4.67%, respectively. However, high-intensity training at 85% 1RM resulted in much larger increases of 18.3% and 6.5%, respectively [17]. Similarly, Ozaki and colleagues demonstrated that low-intensity bench press with BFR increased 1RM by 8.7%, while training at 75% 1RM led to a twofold greater increase of 17.7% [29].

Furthermore, several studies highlighted that strength gains were clearly suboptimal when low-intensity resistance training was performed without BFR. For example, when comparing programs using 8-12 RM and 20-25 RM, it was found that 1RM improvements in bench press and leg press were considerably lower in the higher-repetition range

(8% vs 14.1% for bench press and 29.4% vs 41.9% for leg press) [30].

We proposed that incorporating a few high-intensity sets into a low-intensity resistance training program with BFR could enhance maximal strength gains to levels comparable to those achieved through high-intensity training alone. This approach addressed the issue of suboptimal strength gains associated with low-intensity training [13]. Previous studies supported this rationale, showing that high-intensity sets performed to failure result in greater neural adaptations compared to low-intensity training to failure [31]. Additionally, Schoenfeld and colleagues noted that low-intensity training to failure might not fully engage the entire motor unit pool, particularly the stronger fast-twitch fibers, which are typically recruited later in the process [32]. This insufficient activation of fast-twitch fibers could compromise muscle strength adaptations. By including high-intensity sets, lifters could ensure the recruitment of these fibers, likely contributing to the comparable strength gains observed in our study. However, as mentioned earlier, it may not have been necessary to employ high-intensity efforts in every set to achieve maximal adaptations. The approach used in this study, incorporating high-intensity sets for only half of the total volume, may have been sufficient for optimizing strength gains in novice lifters.

This study was not without limitations. While its strength lay in confirming muscle strength improvements through various testing methods, which enhanced the validity of our findings, there are areas requiring further investigation. Firstly, this study was conducted with novice lifters, and the results might not be directly applicable to more experienced individuals. Future research should examine this protocol with trained participants to verify its effectiveness across different experience levels. Additionally, exploring other muscle groups would be beneficial to determine if similar benefits can be observed.

Conclusions

This study demonstrated that achieving maximum strength gains does not require high-intensity training in every set. Both TSP and CSP, which included high-intensity sets for only half of the training volume, produced comparable improvements in strength metrics over 6 weeks. The effectiveness of CSP underscores the potential for optimizing strength gains with a more varied approach to intensity. Moreover, this approach can offer benefits in terms of reduced fatigue and enhanced recovery, making it particularly suitable for novice lifters. Future research should explore the long-term effects of this training strategy and its applicability to more experienced athletes and other muscle groups.

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ORIGINAL ARTICLE

Attack efficiency in first league men's volleyball for playing positions, according to the value level of the teams

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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 attack is a crucial technical element in scoring points in volleyball. This research aims to identify differences in attack efficiency and errors based on the value level of teams in the competitive system, considering different playing positions.

Material and Methods The analysis included 86 attacking players from the rosters of 12 teams in the men's domestic first league. The distribution by positions was as follows: 37 outside hitters, 19 opposites, and 30 middle blockers. Statisticians from each team recorded the data using Data Volley software during three championship matches. For each player, the following parameters were interpreted: Attack Efficiency (E%), Error% (=), Blocked Attack% (/), Poor% (-), Blocked but Recovered% (!), Positive% (+), and Winning% (#). Attack efficiency was analyzed for each playing position across top teams (positions 1-4 in the final ranking), mid-level teams (positions 5-8), and lower-level teams (positions 9-12).

Results Across all three playing positions, top teams demonstrate higher percentages in attack efficiency, winning executions, and positive outcomes compared to average and lower-level teams. Top and average teams also have lower percentages of errors in attack executions. For the outside hitter position, no statistically significant superiority is observed between top and middle teams for any attack variable, indicating a balance in player performance. In the opposite hitter position, top and middle-level players show higher attack efficiency and direct point scores (Winning). They also have lower poor execution rates, despite the lack of statistical confirmation for superiority in many attack variables. Among all positions, top middle blockers exhibit a clear superiority over low-level teams across all attack variables.

Conclusions The findings of the study highlight the critical role of team value level in influencing attack efficiency and execution quality across different playing positions in volleyball. The results underscore the importance of strategic differentiation in training and game planning. This is especially crucial for teams aiming to optimize their performance. Coaches and trainers should focus on tailored approaches that address the specific strengths and weaknesses of each playing position. They should also consider the overall team value level in their strategies. This approach could lead to improved competitive outcomes and a more effective utilization of player potential across all levels of competition.

Keywords: performance analysis, positional roles, team value level, error rates

Introduction

Volleyball is one of the most popular sports, where attack efficiency is crucial for winning matches. However, despite the importance of attacking actions, the differences in attack efficiency and error rates among teams of varying levels require the search for more effective solutions. This concern is particularly relevant when considering specific playing positions. Addressing this gap calls for a deeper analysis and understanding of how team level and playing position influence attack performance in competitive settings.

In this context, research on various approaches to improving attacking actions and enhancing team efficiency has become increasingly relevant. Volleyball and other ball sports influence the coordination processes and anthropometric dimensions of the participants [1, 2, 3]. Used in physical education and leisure, these activities promote a healthy lifestyle [4]. Volleyball is an extremely dynamic sport, requiring players to quickly analyze and process information and game situations. This ability facilitates adaptation and finding solutions to disrupt the opposing team [5]. The fundamental role of attack, particularly the spike as a phase for accumulating points, compared to defense, is well-documented in elite men's volleyball within the European League [6]. Fast attacks are predominantly observed in higher age categories/senior teams, showing higher effectiveness. An increased use of attack in the first and second tempo has been identified across all age groups [7]. Elite men's volleyball often involves system situations, providing optimal conditions for constructing attacks [8]. Winning points in a typical

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set during volleyball tournaments is influenced by the effectiveness of the attack following reception, as well as the success rate of the breakpoint complex [9]. For volleyball teams participating in the Olympic Games, receptions that facilitated well-organized attacks significantly improved the teams' chances of winning points [10].

These findings underscore the critical importance of attack strategies in volleyball, particularly at the elite level, where effective execution can decisively influence match outcomes. As such, understanding and optimizing attack efficiency remains a key focus for teams aiming to achieve competitive success.

The factors that influence outcomes in men's volleyball matches in Puerto Rico and ensure competitive success are varied. Complex I and II efficiency, blocking points, point service, and points in attack are some predictors of the results [11]. Technical indicators that ensure the victory of men's volleyball teams in the Olympic Games and World Championships are analyzed by [12]. For matches completed in 3-4 sets, the most important predictor is attack, but for those completed in 5 sets, points accumulated from serve and block play a major role. The use of Social Network Analysis provides detailed and more refined information about the influence of actions and game variables associated with attacks in volleyball [13]. Statistical analysis of volleyball matches is becoming increasingly important for coaches, as they capitalize on the data provided to improve training programs [14]. The application of logistic regression models in the Turkish Men's Volleyball League facilitates the explanation of results in official matches. The efficiency of different players/positions (middle blocker, setter, outside hitter, opposite/universal) predicts winning or losing matches by more than 80% [15].

These studies highlight the diverse factors that contribute to match outcomes, emphasizing the critical role of specific technical indicators and player efficiency. Understanding these variables allows teams to refine their strategies and enhance their competitive edge.

During volleyball matches, the playing positions of the players and their value/sport level may influence the number of jumps executed and their intensity. Individualized training is recommended according to the specialization of the players by position [16]. Other studies also analyze the individualization of jump training in volleyball players, considering the playing position, correlated with the number and height of jumps. The highest jump heights (96.5%) are recorded for jumps executed during attacks, with lower values for blocks (88.8%) and serves (81.5%) [17]. Other sources analyzing elite Brazilian men's volleyball highlight the necessity of using backrow attackers (positions 1 and 6), which increases scoring chances due to the uncertainty created for the opposing team [18]. In Brazilian volleyball at the elite level, predictive factors for the attack performed by the opposite player from positions 1 and 2 are analyzed by [19]. Offensive strategies often require the implementation of a system with four attacking players [20].

These findings underscore the importance of position-specific training and the strategic use of backrow attackers to enhance offensive performance. By tailoring training to player positions and employing varied offensive systems, teams can significantly improve their effectiveness during matches.

Side out attack (attack after reception) efficiency is crucial for winning points and sets in volleyball. In situations where the side out attack is unsuccessful or missed, the setter's decision-making becomes critical. Executing a faster attack tempo is an effective solution in these cases [21]. Players' movements on the court are determined by the tasks associated with their playing position. The setter covers the longest distances during sets, while the middle blockers cover the shortest, with a significant difference between these two positions [22]. Research on world-class men's volleyball players has shown a significant relationship between the middle blocker and setter positions, influencing the attack area [23]. Attack efficiency is heavily dependent on quick decision-making by the setter and the middle blocker's choice for the pass when available [24]. For men's volleyball teams at the Olympic level, attack efficiency is conditioned by the setter's prior performance. This enables successful points from 1st or 2nd tempo attacks [25]. Another study corroborates this, demonstrating that better setter performance leads to higher attack player performance, particularly for those participating in the Olympic Games [26].

These findings emphasize the critical role of the setter in optimizing attack efficiency, especially in high-stakes matches. A well-coordinated effort between the setter and attack players can significantly enhance a team's chances of winning points and sets.

The different playing position tasks in men's volleyball impose variations in the somatotype of each specialization/position on the court, as highlighted in Croatian national league volleyball players [27]. Height and vertical jump values are key performance determinants in men's volleyball, with significant differences identified between outside hitters, middle blockers, and opposites [28]. A comparison of the somatic traits of Indian college volleyball players indicates significant differences between the profiles of middle blockers and outside hitters. Middle blockers are taller and have a higher ectomorph component, while outside hitters are heavier and more mesomorphic. These aspects contribute to the understanding of the peculiarities of the playing positions and the preparation of players for the attack phase [29]. A comparative analysis of anthropometric parameters for male volleyball players in the Ethiopian League shows differences between playing positions. Middle blockers, followed by outside hitters and opposites, have the highest values of height and weight among those involved in attacks [30]. An investigation of anthropometric parameters in the top two value leagues in Italian men's volleyball highlights the need to improve shoulder flexibility and mobility. Among the players involved in attacks, opposites and middle hitters are the heaviest and tallest, with higher values in upper limb length widths and contracted arm circumference [31]. Height and body weight are positively and significantly associated with attack efficiency in men's volleyball. For national teams participating in a European tournament (Croatia, Italy, France, and Estonia), middle blockers are the tallest and execute the most blocks, while outside hitters and opposites have average height but stand out with the highest attack load. Setters execute the fewest attacks [32]. For the setter position, attack execution is recommended to be preceded by a high-quality pass. Although less common in men's volleyball, setter attacks can be a way to diversify a team's attack options [33].

These findings underscore the critical role that somatotype and anthropometric characteristics play in determining the performance of players in different volleyball positions. Tailoring training and strategy to these physical attributes can significantly enhance attack efficiency and overall team performance.

Investigations in volleyball players of different age groups in national teams (Brazil, Argentina, Australia, Canada) identify differences in position profiles. Middle blockers are taller and heavier than outside hitters and setters. Additionally, attack and block jumps occur more frequently for middle blockers. Vertical jump and spike jump values are highest for middle blockers and outside hitters [34]. Testing elite volleyball players in Iran revealed significant differences in muscle strength performance tests for attack players. Middle blockers performed worse, but no significant differences were found between outside hitters, opposites, and middle blockers in agility tests [35]. The comparison between the profiles of Brazilian volleyball players (U19) indicates that middle blockers and opposites (attack players) have superior anthropometric dimensions. These positions also show higher values in vertical jumps (spike jump and block jump) compared to defensive players (libero and setters) [36]. The profile of middle blockers highlights their superior height, weight, block jump height, and spike/attack height. They also exhibit a higher frequency of jumping during matches, which is crucial in tempo 1 attacks [37]. The relationship between vertical jump height and unsuccessful attack executions in Turkish high-level players was analyzed by [38]. The data indicate that negative attacks (errors, blocked attacks, and poor attacks) are not significantly correlated with jump values for middle blockers. However, for opposites, only weak positive correlations were found between jump height and points lost due to attack errors [38].

These findings emphasize the distinct physical and performance profiles required for different volleyball positions, particularly for middle blockers and opposites. Understanding these differences is crucial for optimizing training programs and enhancing match performance.

Most of the analyzed studies make a strong case for the critical role that specific physical and performance profiles play in determining success in men's volleyball. Middle blockers and opposites consistently show superior height, weight, and vertical jump abilities, which are essential for effective attack and block executions. The findings underscore the importance of individualized training tailored to the unique demands of each playing position. Additionally, the studies highlight the strategic value of setter performance and the frequency of jumps, particularly in high-level competitive settings. However, there remains a challenge in fully understanding and optimizing the interaction between these physical attributes and tactical decisions during matches. In this context, the aim of the research is to identify the differences in efficiency and errors for attack, depending on the value level of the teams in the competitive system, separated by playing positions. For this purpose, the following hypotheses were formulated:

- H1: Significant differences in the parameters of attack efficiency are expected between top, middle, and low-level teams for outside hitters.
- H2: Significant differences in the parameters of attack efficiency are expected between top, middle, and low-level teams for opposite hitters.
- H3: Significant differences in the parameters of attack efficiency are expected between top, middle, and low-level teams for middle blockers.

Materials and Methods

Participants

The analyzed group includes all players in attacking positions from the Romanian men's volleyball first league national championship (2017-2018 season). A total of 86 attacking players from the 12 participating teams were analyzed: 37 outside hitters, 19 opposites, and 30 middle blockers. The age of the participants ranges from 18 to 35 years.

Research Design

The data were recorded by each team's statisticians using Data Volley software during three matches of the return championship. The data were provided to the Human Performance Research Centre of the Faculty of Physical Education and Sports of Galati in 2024. For each player, the following parameters were analyzed: Attack Efficiency (E%), Error% (=), Blocked attack% (/), Poor% (-), Blocked but recovered% (!), Positive% (+), and Winning% (#). The codes and their interpretations related to the quality and efficiency of the attack are provided in the Data Volley book [39]. Attack efficiency was analyzed for each playing position across the top teams (positions 1-4 in the final ranking), mid-level teams (positions 5-8), and lower-level teams (positions 9-12). The requirements of scientific research involving human subjects were followed, ensuring the confidentiality of personal data [40, 41]. The publication of the results received approval from the faculty's Ethics Committee (no. 242/10.07.2024).

Statistical Analysis

SPSS Software (Statistical Package for the Social Sciences, IBM, Version 24, Chicago, IL, USA) was used to transfer the individual data and calculate the differences in the dependent variables across the three value levels of the championship. The total number of attacks and the mean values for the entire group, as well as separately by the three playing positions, are summarized in Table 1. The normality of the data distribution was assessed using the Shapiro-Wilk test. The Kruskal-Wallis test was employed to identify the significance of differences between the three value levels for each playing position. The significance of differences within each value pair (top vs. middle, middle vs. low, and top vs. low) was determined using the Mann-Whitney U test. The confidence interval was set at 95% [42, 43, 44, 45].

Results

The comparison of values between positions indicates the superiority of middle blockers for E% and Winning%. This group also has the lowest scores for Error%, Blocked attack%, and Poor%. The significance of differences between the three groups was not further calculated, as the efficiency of middle blockers is evident and can be explained by their favorable attack execution positions. In terms of mean values for the number of attacks per playing position, opposites rank first, followed by outside hitters, with middle blockers last.

The average values of the variables analyzed for the outside hitter position at the three ranking levels are shown in Figure 1. Players in the top group have the best percentages for E%, Positive%, and Winning% (which directly contributes to scoring points), while the low group has the worst values. The Blocked but Recovered% variable has the highest score in the middle group. The low group shows higher percentages in categories associated with mistakes, such as Error%, Blocked Attack%, and Poor%.

The significance of the differences between the medians of the three groups at the outside hitter specialization level is shown in Table 2. The χ^2

Table 1. Mean values of the independent variables for the 3 specialisations by positions at the level of the whole lot.

Group	**Whole group N=86 (3515 attacks)**		**Outside hitter N=37 (1611 attacks)**		**Opposite N=19 (1234 attacks)**		**Middle blocker N=30 (670 attacks)**	
Variables	**Mean**	**Std. deviation**	**Mean**	**Std. deviation**	**Mean**	**Std. deviation**	**Mean**	**Std. deviation**
Attack Efficiency (E%)	24.488	13.584	20.027	13.348	23.105	8.245	30.866	13.584
Total attack executions	40.872	27.558	43.540	23.703	64.947	33.781	22.333	8.707
(=) Error executions	4.127	3.446	4.351	3.417	6.789	4.035	2.166	1.23
Error%	10.069	3.978	10.000	4.189	10.578	4.694	9.833	3.270
Blocked attack executions	3.837	3.490	4.054	3.265	6.789	4.144	1.700	1.149
Blocked attack%	8.930	4.423	9.135	5.207	10.315	3.198	7.800	3.836
Poor executions	6.480	5.427	7.540	5.156	10.050	6.390	2.900	2.218
Poor%	14.941	6.225	16.567	6.217	15.473	6.449	12.600	5.537
Blocked but recovered executions	3.220	2.019	3.783	2.070	3.947	2.146	2.066	1.284
Blocked but recovered%	9.162	4.637	9.837	4.734	6.842	3.287	9.800	4.894
Positive executions	5.430	4.263	5.891	3.717	8.526	5.796	2.900	1.446
Positive%	13.360	4.246	13.918	5.330	12.789	3.750	13.033	4.246
Winning executions	17.860	12.652	17.864	10.919	28.894	16.512	10.866	4.644
Winning%	43.674	9.070	40.000	9.070	43.947	5.338	48.033	9.474

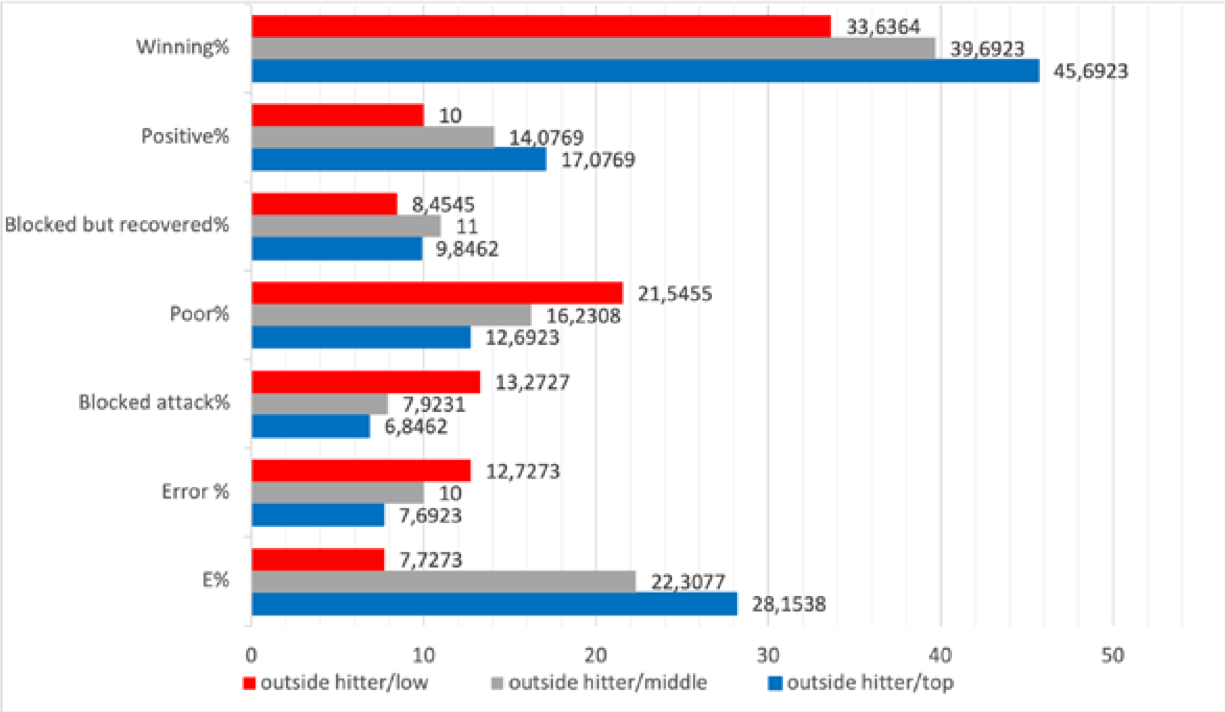

Figure 1. Average attack efficiency values and percentages for the 6 execution variants at the outside hitter specialisation levels (top, middle, and low levels)

Table 2. Kruskal Wallis test values for the outside hitter specialisation for the 3 levels of ranking (top, middle and low)

Variables	Chi-Square/χ2	df	Sig.
E%	15.890	2	.000
Error%	8.767	2	.012
Blocked attack%	10.310	2	.006
Poor%	12.200	2	.002
Blocked but recovered%	0.726	2	.696
Positive%	12.043	2	.002
Winning%	11.906	2	.003

values indicate significant thresholds for E% and all attack variants except for Blocked but Recovered% ($P > 0.05$).

The differences between the top and middle groups for outside hitters do not show any significant difference ($P > 0.05$), as indicated in Table 3. Therefore, there is a value balance in terms of attacking for this specialization between these two categories, which is a unique aspect among all the compared pairs.

In the comparison between the middle and low groups for outside hitters, significant differences in favor of the middle group are found for E%, Positive%, and Winning%. The low group has significantly higher scores for Blocked Attack% and Poor% ($P < 0.05$). No significant differences are identified for Error% and Blocked but Recovered%, as shown in Table 4.

The differences in mean rank between the top and low levels for outside hitters are summarized in Table 5. Top players have significantly better scores for E%, Positive%, and Winning%. Low-level players have higher values for Error% and unsuccessful attack variants. The only insignificant difference is for Blocked but Recovered% ($P > 0.05$).

Figure 2 shows the average scores for the opposite play position at the three value levels of the ranking. Once again, the top teams have higher E% values and higher percentages for favorable attack executions, while the low-level teams have the lowest values. Errors and mistakes in attack execution have higher values for the low-level teams, followed by the middle-level teams. The only independent variables where there are close scores across the three value levels are Blocked Attack% and Blocked but Recovered%.

Table 6 presents the significance of the differences between the medians of the three value

Table 3. Mann Whitney U test results for the comparison of the outside hitter top vs outside hitter middle result pair

Variables	Outside hitter/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	13	15.77	205.00	55.000	-1.515	.130
	middle	13	11.23	146.00			
Error%	top	13	11.54	150.00	59.000	-1.314	.189
	middle	13	15.46	201.00			
Blocked attack%	top	13	12.35	160.50	69.500	-.778	.436
	middle	13	14.65	190.50			
Poor%	top	13	11.15	145.00	54.000	-1.572	.116
	middle	13	15.85	206.00			
Blocked but recovered%	top	13	12.77	166.00	75.000	-.490	.624
	middle	13	14.23	185.00			
Positive%	top	13	15.12	196.50	63.500	-1.081	.280
	middle	13	11.88	154.50			
Winning%	top	13	16.19	210.50	49.500	-1.799	.072
	middle	13	10.81	140.50			

Table 4. Mann Whitney U test results for the comparison of the outside hitter middle vs outside hitter low outcome pair

Variables	Outside hitter/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	middle	13	16.54	215.00	19.000	-3.044	.002
	low	11	7.73	85.00			
Error%	middle	13	9.96	129.50	38.500	-1.924	.054
	low	11	15.50	170.50			
Blocked attack%	middle	13	9.46	123.00	32.000	-2.299	.022
	low	11	16.09	177.00			
Poor%	middle	13	9.88	128.50	37.500	-1.977	.048
	low	11	15.59	171.50			
Blocked but recovered%	middle	13	13.73	178.50	55.500	-.933	.351
	low	11	11.05	121.50			
Positive%	middle	13	15.65	203.50	30.500	-2.386	.017
	low	11	8.77	96.50			
Winning%	middle	13	15.27	198.50	35.500	-2.088	.037
	low	11	9.23	101.50			

groups for the opposite specialization. The χ^2 results are significant only for E%, Winning%, Positive%, and Poor%.

The significance of the differences between the top and middle levels for the opposite position is shown in Table 7. The Z values are significant for E%, Winning%, and Positive% in favor of the top group, and for Poor% in favor of the middle group.

The significance of the differences between the middle and low levels for the opposite position is summarized in Table 8. The Z values are significant only for E% and Winning% in favor of the middle group, and for Poor% in favor of the low group. No significant differences were identified for the other comparisons.

The significance of the differences between the top and low levels for the opposite position is shown in Table 9. The Z values are significant for E%, Winning%, and Positive% in favor of the top group, and for Poor% in favor of the low group. However, the higher scores for Error% and Blocked Attack% in the low group are not significant ($P > 0.05$).

Figure 3 shows the average scores for the middle blocker position across the three value levels. As with the other positions, E%, Winning%, and Positive% have higher values at the top level, followed by the

Table 5. Mann Whitney U test results for comparing the outside hitter top vs outside hitter low outcome pair

Variables	Outside hitter/ Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	13	17.23	224.00	10.000	-3.569	.000
	low	11	6.91	76.00			
Error%	top	13	8.81	114.50	23.500	-2.804	.005
	low	11	16.86	185.50			
Blocked attack%	top	13	8.38	109.00	18.000	-3.120	.002
	low	11	17.36	191.00			
Poor%	top	13	7.92	103.00	12.000	-3.466	.001
	low	11	17.91	197.00			
Blocked but recovered%	top	13	12.65	164.50	69.500	-.118	.906
	low	11	12.32	135.50			
Positive%	top	13	16.96	220.50	13.500	-3.376	.001
	low	11	7.23	79.50			
Winning%	top	13	16.77	218.00	16.000	-3.220	.001
	low	11	7.45	82.00			

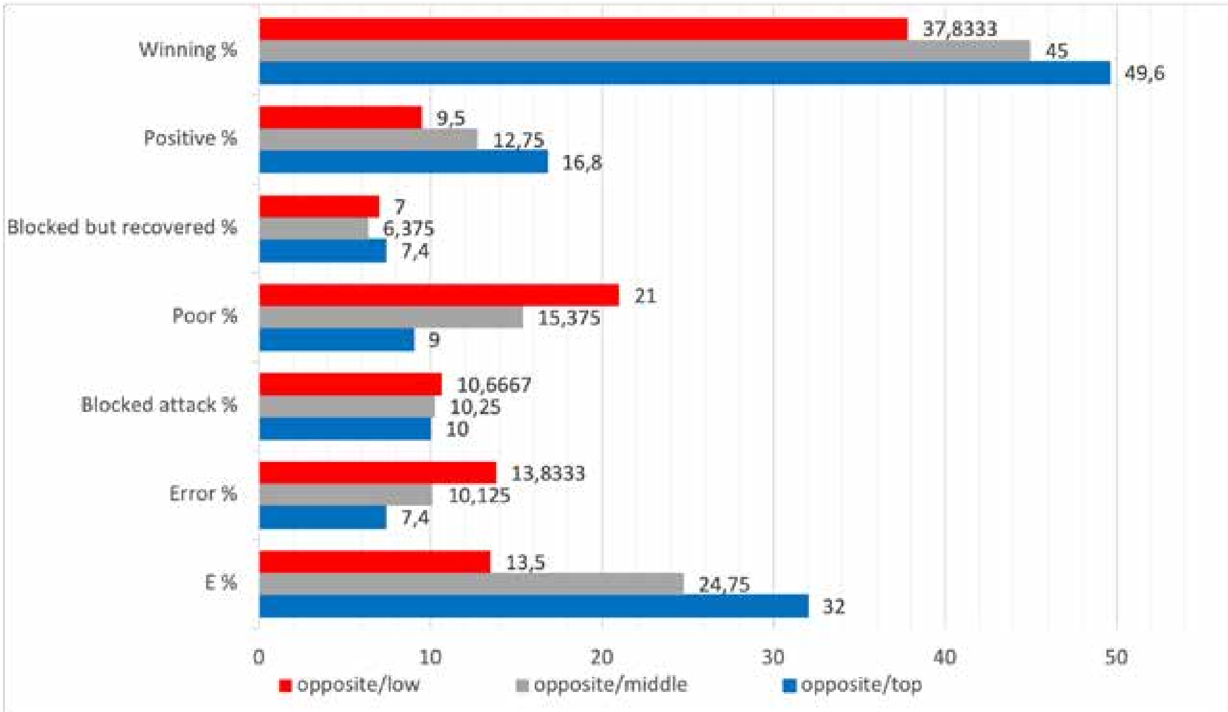

Figure 2. Average attack efficiency values and percentages for the 6 execution variants at opposite specialisation (top, middle, and low levels)

middle level. Mistakes and poor attack execution have higher percentages in the low-value group. In contrast to the other two positions, the middle blocker position shows a higher percentage for the Blocked but Recovered% variant in the low group, while the top and middle groups have lower and nearly equal values.

Table 10 shows the significance of the differences between the medians of the three value groups for the middle blocker position. The χ^2 results are significant for all the independent variables analyzed, a result not found for the other two playing positions.

The differences between the top and middle groups for middle blockers are statistically significant in favor of the top group only for E% and Winning%. The middle group has only one significantly higher value, namely Error% ($P < 0.05$), as shown in Table 11.

The comparison between the values of the middle and low groups for the middle blocker position indicates the significant superiority of the

Table 6. Kruskal Wallis test values at the opposite specialisation for the 3 ranking levels (top, middle, and low)

Variables	Chi-Square/χ2	df	Sig.
E %	15.334	2	.000
Error %	4.478	2	.107
Blocked attack %	.191	2	.909
Poor %	11.236	2	.004
Blocked but recovered %	.614	2	.736
Positive %	11.843	2	.003
Winning %	13.896	2	.001

Table 7. Mann Whitney U test results for opposite top vs opposite middle outcome pair comparison

Variables	Opposite/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	5	10.70	53.50	1.500	-2.742	.006
	middle	8	4.69	37.50			
Error%	top	5	5.10	25.50	10.500	-1.418	.156
	middle	8	8.19	65.50			
Blocked attack%	top	5	6.70	33.50	18.500	-.222	.825
	middle	8	7.19	57.50			
Poor%	top	5	3.70	18.50	3.500	-2.422	.015
	middle	8	9.06	72.50			
Blocked but recovered%	top	5	8.00	40.00	15.000	-.736	.462
	middle	8	6.38	51.00			
Positive%	top	5	11.00	55.00	.000	-2.956	.003
	middle	8	4.50	36.00			
Winning%	top	5	10.30	51.50	3.500	-2.432	.015
	middle	8	4.94	39.50			

Table 8. Mann Whitney U test results for the opposite middle vs opposite low outcome pair comparison

Variables	Opposite/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	middle	8	10.50	84.00	.000	-3.112	.002
	low	6	3.50	21.00			
Error%	middle	8	6.31	50.50	14.500	-1.236	.216
	low	6	9.08	54.50			
Blocked attack%	middle	8	7.19	57.50	21.500	-.325	.745
	low	6	7.92	47.50			
Poor%	middle	8	5.56	44.50	8.500	-2.014	.044
	low	6	10.08	60.50			
Blocked but recovered%	middle	8	7.13	57.00	21.000	-.389	.697
	low	6	8.00	48.00			
Positive%	middle	8	8.94	71.50	12.500	-1.501	.133
	low	6	5.58	33.50			
Winning%	middle	8	10.31	82.50	1.500	-2.921	.003
	low	6	3.75	22.50			

Table 9. Mann Whitney U test results for the opposite top vs opposite low outcome pair comparison

Variables	Opposite/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	5	9.00	45.00	.000	21.000	.006
	low	6	3.50	21.00			
Error%	top	5	4.00	20.00	5.000	20.000	.065
	low	6	7.67	46.00			
Blocked attack%	top	5	5.60	28.00	13.000	28.000	.712
	low	6	6.33	38.00			
Poor%	top	5	3.00	15.00	.000	15.000	.007
	low	6	8.50	51.00			
Blocked but recovered%	top	5	6.50	32.50	12.500	33.500	.646
	low	6	5.58	33.50			
Positive%	top	5	9.00	45.00	.000	21.000	.006
	low	6	3.50	21.00			
Winning%	top	5	9.00	45.00	.000	21.000	.006
	low	6	3.50	21.00			

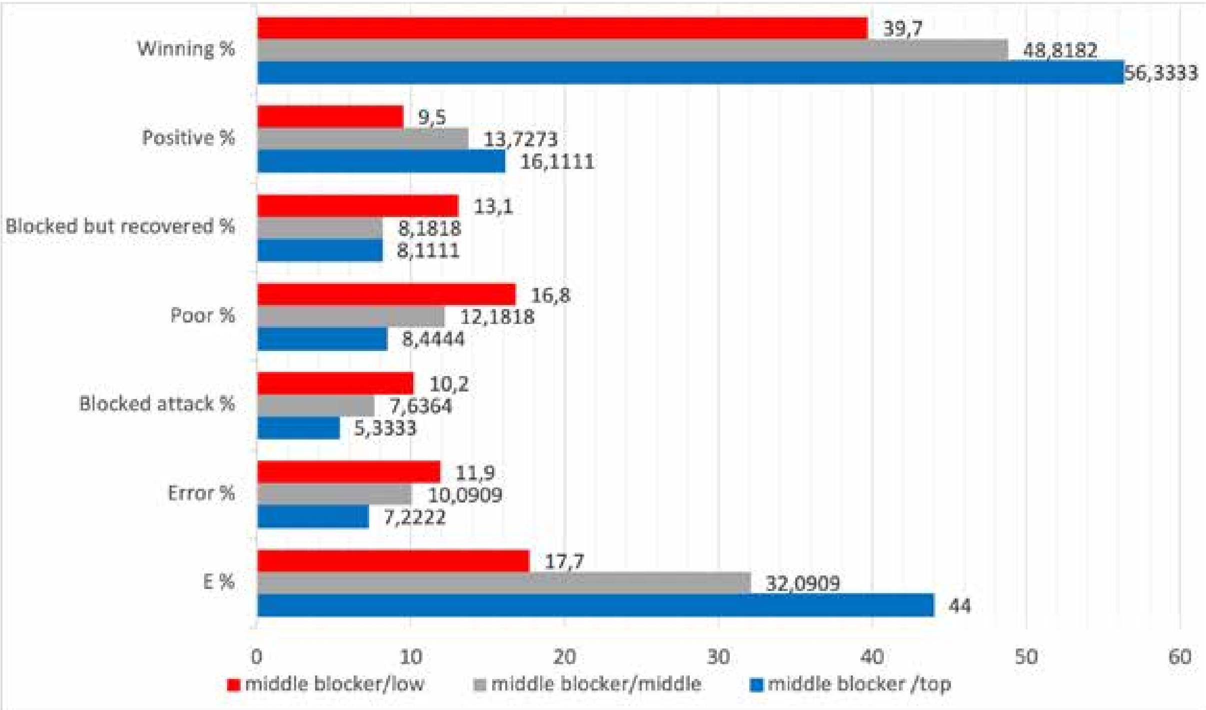

Figure 3. Average attack efficiency values and percentages for the 6 execution variants at the middle blocker levels (top, middle, and low levels)

Table 10. Kruskal Wallis test values for the middle blocker specialisation for the 3 ranking levels (top, middle and low).

Variables	Chi-Square/$\chi 2$	df	Sig.
E%	19.232	2	.000
Error%	10.450	2	.005
Blocked attack%	7.101	2	.029
Poor%	9.418	2	.009
Blocked but recovered%	6.431	2	.040
Positive%	13.537	2	.001
Winning%	16.349	2	.000

Table 11. Mann Whitney U test results for the comparison of the middle blocker top vs middle blocker middle outcome pair

Variables	Middle blocker/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	9	14.22	128.00	16.000	-2.551	.011
	middle	11	7.45	82.00			
Error%	top	9	7.61	68.50	23.500	-1.990	.047
	middle	11	12.86	141.50			
Blocked attack%	top	9	8.39	75.50	30.500	-1.480	.139
	middle	11	12.23	134.50			
Poor%	top	9	7.72	69.50	24.500	-1.911	.056
	middle	11	12.77	140.50			
Blocked but recovered%	top	9	9.83	88.50	43.500	-.461	.645
	middle	11	11.05	121.50			
Positive%	top	9	12.61	113.50	30.500	-1.454	.146
	middle	11	8.77	96.50			
Winning%	top	9	13.50	121.50	22.500	-2.058	.040
	middle	11	8.05	88.50			

Table 12. Mann Whitney U test results for the comparison of the middle blocker middle vs middle blocker low outcome pair

Variables	Middle blocker/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	middle	11	15.00	165.00	11.000	-3.107	.002
	low	10	6.60	66.00			
Error%	middle	11	9.36	103.00	37.000	-1.280	.201
	low	10	12.80	128.00			
Blocked attack%	middle	11	9.09	100.00	34.000	-1.491	.136
	low	10	13.10	131.00			
Poor%	middle	11	8.91	98.00	32.000	-1.629	.103
	low	10	13.30	133.00			
Blocked but recovered%	middle	11	8.00	88.00	22.000	-2.343	.019
	low	10	14.30	143.00			
Positive%	middle	11	14.77	162.50	13.500	-2.940	.003
	low	10	6.85	68.50			
Winning%	middle	11	14.77	162.50	13.500	-2.936	.003
	low	10	6.85	68.50			

middle group for E%, Winning%, and Positive%. The low group of athletes has significantly better values only for Blocked but Recovered%. No significant differences were found for errors, blocked attacks, and poor executions, where the low group stands out with higher values, as shown in Table 12.

The significance of the differences between the top and low levels for the middle blocker position is shown in Table 13. The Z values are significant for all independent variables analyzed ($P < 0.05$). This is the only comparison between the top and low levels where such a result is reported.

Discussion

The primary aim of this study was to identify the differences in attack efficiency and errors across different playing positions, based on the value level of teams in the Romanian men's volleyball first league. The results revealed that the average number of executions per playing position indicates a higher frequency for opposites, followed by outside hitters, and finally middle blockers. However, middle blockers have the best values for E% and Winning%. These players also have the lowest percentages for

Table 13. Mann Whitney U test results for the comparison of the middle blocker top vs middle blocker low outcome pair

Variables	Middle blocker/Level	N	Mean Rank	Sum of Ranks	Mann Whitney U	Z	Sig. (2 tailed)
E%	top	9	15.00	135.00	.000	-3.681	.000
	low	10	5.50	55.00			
Error%	top	9	5.67	51.00	6.000	-3.201	.001
	low	10	13.90	139.00			
Blocked attack%	top	9	6.61	59.50	14.500	-2.520	.012
	low	10	13.05	130.50			
Poor%	top	9	6.17	55.50	10.500	-2.832	.005
	low	10	13.45	134.50			
Blocked but recovered%	top	9	7.33	66.00	21.000	-1.968	.049
	low	10	12.40	124.00			
Positive%	top	9	14.22	128.00	7.000	-3.119	.002
	low	10	6.20	62.00			
Winning%	top	9	14.72	132.50	2.500	-3.481	.000
	low	10	5.75	57.50			

incorrect executions, including Error%, Blocked Attack%, and Poor%. Across all three attacking positions, top teams have higher percentages for attack efficiency and executions categorized as winning and positive, compared to middle and low-level teams. Top and middle teams also have lower percentage scores for attack executions with errors.

For the outside hitter position, the superiority of the top vs. middle teams is not statistically confirmed for any of the attack variables, indicating a balance between the value of these players. Significant differences were identified for most variables between the top and low teams (except for Blocked Attack%). Differences were also statistically confirmed between middle and low teams (except for Blocked Attack% and Blocked but Recovered%). Low-level teams have players with lower efficiency in this position.

For the opposite hitter position, the superiority of the top vs. middle teams is statistically confirmed only for E%, Positive%, and Winning%. Opposites from the top teams also have significantly lower values for Poor% executions, but for other types of inefficient executions, no significant differences were reported. However, significant differences were observed between the top and low teams for four variables: E%, Winning%, Positive%, and Poor%. For the middle vs. low comparison, fewer significant differences were identified; middle-level teams had better values only for E% and Winning%, and lower values for Poor%. This suggests a more balanced distribution of values among teams of different levels for this position. Nevertheless, top and middle-level teams have the advantage of higher attack efficiency and more directly scored points (Winning%) and lower values for poor executions.

For the middle blocker position, the superiority of top vs. middle teams is statistically confirmed only for E%, Winning%, and lower Error% values. This indicates that top teams have higher attack efficiency in this position due to more directly won points and lower error percentages. A similar situation is observed for the middle vs. low comparison. In the top vs. low comparison, significant differences were identified for all analyzed variables, indicating that among all the attacking positions, middle blockers from top-level teams hold a clear advantage over those from low-level teams.

Analyzing volleyball matches provides important information for coaches about the challenges faced by their teams. The results facilitate targeted interventions to improve specific game phases. Statistical analysis has indicated that a faster first-tempo attack is the most effective action during the offensive phase [46]. Defeats in volleyball matches are often predictable for teams lacking attack-related skills. For teams participating in the Men's Volleyball World Championship, the difference between winners and losers is often determined by factors such as serve points, excellent digs, attack errors, and service errors [47]. An analysis of the Men's Championship League revealed significant differences between winning and losing teams in terms of attacks. Winners are more efficient in executing spikes from different areas of the court, both in attacks and counterattacks [48]. A longitudinal study analyzing success factors for Greek men's championship teams over 12 seasons identifies the importance of winning on the first attack. This factor distinguishes top teams from mid- and low-level teams [49]. Our study confirms the differences between teams' value levels for Winning% and Positive% executions, with top teams demonstrating superior performance.

Other studies have used the Bayesian hierarchical logistic model to estimate the contribution of volleyball playing positions and the players occupying those positions to team success or failure [50]. Using a similar investigative technique, another study highlights the importance of attack speed in men's collegiate volleyball [51]. Victory or defeat in volleyball matches is influenced by several factors, including lost serves, kill-blocks, aces, attack errors, and kill-attacks. However, the best predictors of performance are the Serving Efficiency Ratio (SER) and Attack Efficiency Ratio (AER), which show higher values for top-level men's teams in Greece [52]. Statistical analysis of the efficiency of different technical procedures in the Serbian men's volleyball league highlights the decisive importance of three components: attack, serve, and block efficiency. High values in these areas greatly increase the chances of victory and distinguish the top teams from the weaker ones [53]. Regarding attack efficiency, our investigation indicates higher percentages for the teams ranked higher. We identified significant differences in E% for all positions between the top vs. middle, middle vs. low, and top vs. low groups.

The swing movement is crucial for executing serves and attacks/spikes. Among adolescent volleyball players in China, middle blockers exhibit higher mean values of strength in the execution of swing movements at the arms and trunk compared to outside hitters. However, outside hitters demonstrate better coordination between the lower limbs, trunk, and arms during the swing [54]. A longitudinal analysis of Greek men's volleyball championship matches over 12 seasons highlights the predictors of winning. The most important factors include serve aces, attack after passing or defense, precise passing, and passing errors. For the top teams (positions 1-2 and 3-4), the attack win and attack error parameters show significant differences when compared to lower-ranked teams [55]. Our results indicate significant differences in Error% for the middle blocker position between the top vs. middle and top vs. low groups, but not between the middle vs. low groups. For the outside hitter position, we identified significant differences only in the top vs. low pair. For the opposite position, no significant differences were found for any of the value level pairs.

An investigation of attacks after the 20th point in an international tournament revealed significant differences by position. Most of the attacks in this situation were executed by the opposite, while the middle blocker had the lowest mean Error% and Blocked Attack% [56]. An analysis of the matches in the U23 Men's Volleyball World Championship indicates that attack-spike and block are the most frequently executed technical elements. In terms of players who score the most points, the outside hitter ranks first, followed by the opposite, and finally the middle blocker [57]. A study on Portuguese men's teams in the Portuguese Premier League found differences in the points accumulated by players according to their positions on the court. Outside hitters score slightly more break points than middle blockers and opposites. Increasing efficiency requires improving the counter-attack phase of the game [58]. The opposite player in volleyball is the most relied upon for hitting, with the highest chances of executing successful attacks. In men's volleyball, successful executions are largely dependent on the quality of the ball received from the setters [59]. In the matches we analyzed, the outside hitter had the most total attack executions (1611), followed by the opposite (1234), and the middle blocker (670). However, the average attack values place the opposite in first place (64.94), followed by the outside hitter (43.54), and the middle blocker (22.33).

At the high level of men's volleyball, the importance of variability among players of the same playing position is analyzed. For outside hitters, this understanding helps coaches better assign tasks by recognizing differences between players with the same positional status [60]. A comparative analysis of attack efficiency between outside hitters and opposites at the high level (World Championship) indicates differences between these two positions. Outside hitters have higher success percentages in attack (72.5%), while opposites achieve only 55.1% [61]. In terms of Winning%, our study measured lower values, with the highest being for middle blockers (48.03%), followed by opposites (43.94%), and outside hitters (40.00%).

Attack efficiency depends on the players' positions on the court, according to an analysis of teams participating in the European Championship. Middle blockers have higher efficiency in attacking compared to opposites (spikers) and outside hitters (receivers) [62]. An analysis of offensive phases in high-level Brazilian men's volleyball identified higher efficiency for middle attacks compared to wing and opposite attacks. The efficacy of middle attacks is influenced by powerful attacks, higher quality receptions, and appropriate timing [63]. At the Portuguese men's volleyball championship/ first division level, the predictors of victory include attack efficiency, aces, block points, and the efficacy of points in the defensive phase. For Attack Efficiency%, middle blockers have better values than opposites and outside hitters [64]. These findings are consistent with our results, where middle blockers had the highest E% (30.86%), followed by opposites (23.10%) and outside hitters (20.02%).

Improving muscle strength for repeated jumps in volleyball players is crucial for reducing errors in attack execution. In a study of elite Turkish volleyball players analyzed over two seasons, it was found that the percentage of attack errors increases in middle blockers and outside hitters as the number of vertical jumps increases. However, this trend was not observed for the opposite position [65]. In terms of Error%, our study shows balanced results across the whole group. The highest values are for opposites (10.57%), followed by outside hitters (10.00%) and middle blockers (9.83%).

In summary, this study highlights the significant differences in attack efficiency and error rates across different playing positions and team value levels in the Romanian men's volleyball first league. Middle blockers consistently demonstrated superior performance metrics, particularly in top-level teams, where they exhibited the highest attack efficiency and the lowest error rates. While outside hitters and opposites also showed notable differences in efficiency between value levels, the middle blocker position proved to be the most consistent in differentiating team performance. These findings underscore the critical importance of tailored training strategies and positional roles in optimizing team success in competitive volleyball.

Limitations of the study and future research directions: The large volume of processed data did not allow for an overall comparative presentation of the results across the entire group by value levels (top, middle, and low). Additionally, a more detailed analysis of the attack phases (Complex 1/attack after reception and Complex 2/transition) would provide complementary information to this study.

Conclusions

The findings of this study offer valuable insights for coaches aiming to enhance the performance of their teams across different attacking positions in volleyball. By identifying the strengths and weaknesses specific to each position, coaches can tailor their training programs to address the areas where errors are most prevalent. This targeted approach to training has the potential to significantly improve overall team efficiency, ensuring that athletes are better prepared for the challenges of competitive play. The study underscores the importance of continual assessment and adjustment in coaching strategies to optimize the effectiveness of attack executions and ultimately contribute to team success.

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Conflict of Interest

The authors report no potential conflict of interest relevant to this study.

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ORIGINAL ARTICLE

Analysis of the relationship between upper body speed capacity and lower body strength of elite handball players specialized in winger position

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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 physical demands of the winger position in elite handball require a unique combination of upper body speed and lower body strength. Therefore, identifying the optimal relationship between these two physical characteristics could improve performance for players in this role. This study aims to analyze the relationship between upper body speed capacity and lower body strength in elite handball players specializing in the winger position.

Material and Methods: The study included 16 elite handball players specializing in the winger position from various teams in the National Handball League (Liga Zimbrilor). Four of these players were members of the Dinamo Bucharest team. Tests for evaluating the explosive strength of the lower limbs included the Squat Jump (SJ), Counter Movement Jump (CMJ), Counter Movement Jump with Free Arms (CMJb), and the maximum strength test (1RM) in squats. Specific technical training tests included triangular movement, a 30-meter sprint, and long-distance handball throws, focusing on speed and execution technique. Data analysis was conducted using KyPlot 6.0 software. Statistical indicators included median, standard deviation, coefficient of variation, and non-parametric Spearman correlation tests. Statistical significance was set at $p < 0.05$.

Results: The results show no statistically significant differences in lower limb strength between high-performance handball players (HPHP) and those specialized in the winger position (PSW) across various jump and squat tests ($p > 0.05$). The Countermovement Jump (CMJ) test approached statistical significance ($p = 0.084$), while the CMJ with free arms (CMJb) and squat strength test did not show significant differences ($p = 0.231$ and $p = 0.789$, respectively). In the specific fitness tests, no significant differences were observed in the Triangle Movement test ($p = 0.826$), the 30-meter sprint ($p = 0.404$), or the handball throw test ($p = 0.147$). Correlation analysis indicated that squats and CMJb had positive correlations with improved performance in speed and distance tests, while CMJ showed a negative correlation with technical performance in agility tests.

Conclusions: The findings suggest that lower limb strength and technical fitness are similar between elite handball players, regardless of specialization. This supports a unified training approach across player roles. However, targeted exercises like squats and CMJb may enhance specific performance aspects. These exercises improve dynamic strength and stability, which can benefit wingers' technical execution and speed.

Keywords: elite athletes, speed, explosive strength, correlation analysis

Introduction

Elite handball performance relies on a combination of physical, technical, and tactical factors. Players in the winger position face unique challenges due to their specific role in the dynamics of the game. While upper body speed capacity and lower body strength are critical for wingers, the optimal balance between these attributes remains unclear. Wingers must perform rapid actions, such as passing and shooting, while also requiring explosive strength for jumps and quick direction changes. This gap in understanding the relationship between these physical attributes creates a need for targeted research to optimize training and improve performance in this position.

In this context, the winger position in handball requires a combination of speed, agility, and strength. It is crucial for players to accelerate quickly and execute technical actions, such as shots on goal. These actions are significantly influenced

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by the strength and speed of the upper body muscles, as well as by plyometric and resistance training. This type of training enhances reaction speed and the efficiency of dynamic movements [1, 2]. Given the physical demands of the winger role, understanding how different training approaches impact performance is essential.

Lower body strength enables wingers to perform effective jumps and change direction rapidly. These aspects can be developed through targeted plyometric exercises and strength training. The ability to transfer lower body strength to upper body actions, like jumping and shooting, is critical for on-court performance. Integrated training that combines these elements leads to improved efficiency and muscular coordination during game situations [3, 4, 5, 6]. These findings highlight the necessity of developing both lower body strength and its integration with upper body actions to maximize performance in handball wingers.

Lower body strength not only provides stability but also facilitates the transfer of kinetic energy to the upper body. This transfer helps achieve more powerful and precise executions. In handball, upper body speed and lower body strength work together to enhance performance in complex actions. Developing both capacities is essential for players specializing in the winger position. Lower body strength enables players to gain favorable positions through jumps and accelerations. Upper body speed is critical for converting these physical advantages into efficient technical actions, such as shooting on goal [7, 8]. Together, these elements underscore the need for balanced training programs that address both lower body strength and upper body speed to ensure optimal performance in game situations.

Other research highlights the importance of specific training methods in optimizing performance for elite handball players, emphasizing the role of game-based training and targeted recovery strategies [9, 10, 11]. In addition, studies have demonstrated a close relationship between upper and lower limb strength, power, and throwing speed, underscoring the value of resistance training for improving physical performance and accuracy [3, 12, 13, 14]. In this context, the physical and physiological demands of elite handball require advanced muscle strength and adaptation to high-intensity efforts, which are crucial for enhancing overall performance [5, 15, 16, 17]. Furthermore, variations in training needs based on playing position, such as wingers, suggest that tailored training approaches are essential for addressing the distinct movement profiles and physical capacities of different roles [14, 15]. These studies demonstrate the need for a targeted approach in training programs, taking into account the specific physical demands and requirements of different playing positions to optimize performance in elite handball.

Thus, the performance of handball wingers is determined by a complex interaction between upper body speed and lower body strength, which are crucial for success in executing dynamic movements and technical actions. Despite the recognized importance of these physical attributes, finding the optimal balance between them still requires exploring new, more sophisticated approaches.

This study aims to analyze the relationship between upper body speed capacity and lower body strength in elite handball players specializing in the winger position.

Materials and Methods

Participants

The study involved performance handball players specialized in the winger position (n=16) from several teams participating in the National Handball League (*Liga Zimbrilor*), Romania, out of which (n=4) are members of the *Dinamo* Club Bucharest team.

The consent of the subjects was required and signed before starting the research, according to the Declaration of Helsinki. It was approved by the Ethics Committee of the Doctoral School of Physical Education and Sports Science, the National University of Science and Technology *Politehnica* Bucharest, (ID: 17/24.07.2024), University Center Pitești.

Research Design

In the 2021/2022 competitive season, the senior men's handball team, *Dinamo* Bucharest, participated in the group stage of the Champions League. They won all the competitions they entered at national level (Romanian Cup, National Championship, Romanian Supercup). Most of the players specialized in winger position from the experimental group are or have been members of the national teams.

To conduct the fundamental research, we developed a strength training program together with the coaches and physical trainer of the *Dinamo* Bucharest handball team. The program is based on the periods and stages of the competitive system. It takes into account the participation of the team and players in domestic and international inter-club competitions. The involvement of the players in the national teams is also taken into consideration.

The action systems for developing strength capacity were applied during individualized training sessions. The training was based on playing positions, relative to the one-repetition maximum (1RM) of each athlete of the experimental group.

The strength development training sessions took place in the power gym of the club and on the playing court. The training was carried out according to the competitive system planning and included 2-3 specialized sessions. Also, training sessions of shorter duration and lower intensity, conducted in the form of circuits, were carried out before official matches.

Tests to assess lower limbs strength:

Squat Jump (SJ) Test: starting from a semi-squat position with hands on hips, the participant performs a jump as high as possible, ensuring that the knees are fully extended during the flight. The landing is done on two feet, without any subsequent movement.

Counter Movement Jump (CMJ) Test: from a standing position with feet slightly apart and hands on hips, the participants flex their legs in a quick, continuous motion until reaching a semi-squat position, after which they perform a vertical jump. While in the air, the knees must be extended.

Counter Movement Jump Free Arms (CMJb) Test: from a standing position with arms free and feet slightly apart, the participants flex their legs in a quick, continuous motion until reaching a semi-squat position, after which they perform a vertical jump. While in the air, the knees must be extended.

Maximum Strength Test (1RM) - *Squats*: representing the maximum repetition that can be performed, the 1RM test (one-repetition maximum) has a high degree of reliability. It establishes the maximum strength level of a muscle or muscle chains. This test determines a more precise, individualized and differentiated periodization of the training process aimed at maximizing athletic performance. From a standing position with feet shoulder-width apart and toes slightly turned outward, the athletes keep a barbell on the back. Maintaining a straight back, they flex their legs so that the hips reach the level of the knees or even lower. Afterwards they return to the initial position.

Specific tests for technical training:

Test 1: Triangle Movement (seconds). This test involves athletes moving between three cones arranged in the shape of an isosceles triangle, with a base and height of 3 meters. Athletes start from the left cone of the base and move in a defensive position with lateral step toward the right cone, then proceed to the apex of the triangle. After reaching the apex, they return to the starting point, following the same trajectory. The test consists of completing two full cycles at maximum speed, with athletes facing outward between the apex and the base of the triangle.

Test 2: 30-Meter Sprint (seconds). Two cones are placed 30 meters apart. From one of the cones, the athletes start a sprint until they pass the other cone, after which they slow down. The start is free and the sprint begins from a stationary standing position.

Test 3: Handball Throw for Distance (meters). After a run-up of three steps, the athlete executes a handball throw for distance from behind a marked line on the ground. Each athlete chooses the throwing technique and the sequence of steps for the run-up.

Statistical Analysis

The statistical indicators were calculated using the KyPlot 6.0 (©1997-2020, KyensLab Inc) program, in terms of Median, Standard Deviation (SD), Coefficient of Variation (CV%), Confidence Level of Mean (0.95) and Confidence Limit of Mean. parametric t-Test (Assuming Equal Variances) Unpaired Comparison for Means; The nonparametric Spearman's correlation coefficient was applied to evaluate the relationship between technical training and motor skills parameters in the elite handball goalkeepers. Statistical significance was set at $p < 0.05$.

Results

The results in Table 1 compare lower limbs strength between high-performance handball

Table 1. Results of the lower body strength in elite handball players specialized in the position of winger

Variables		Mean ± SD	CV (%)	Confidence Level of Mean (0.95)	Confidence Limit of Mean		t	P-value
					Lower	Upper		
Squat jumps	HPHP	34.41 ±3.61	10.48	1.92	32.49	36.33	1.31	0.205
	PSW	31.95 ±1.52	4.75	2.41	29.53	34.36		
CMJ	HPHP	40.3 ±4.88	12.10	2.59	37.70	42.89	1.83	0.084
	PSW	35.67 ±1.89	5.31	3.01	32.66	38.69		
CMJb	HPHP	43.01 ±3.81	8.87	2.03	40.97	45.04	1.24	0.231
	PSW	40.55 ±1.57	3.87	2.49	38.06	43.04		
Squats	HPHP	144.19 ±12.15	8.43	6.47	137.71	150.66	-0.27	0.789
	PSW	146.00 ±10.86	7.44	17.28	128.71	163.28		

Values are expressed as Mean ± Standard Deviations (SD), CV – coefficient of variation; parametric t-Test (Assuming Equal Variances) Unpaired Comparison for Means; HPHP(n=16) – high-performance handball players; PSW(n=4) - players specialized in the position of winger; df = 18; t (0.05) = 2.101

players (HPHP) and those specialized in the winger position (PSW) through various jump and squat tests. The main interpretations are as follows: in the Squat Jump test, HPHP achieved a difference of 2.46 cm greater than PSW ($p > 0.05$). In the CMJ (Countermovement Jump) test, HPHP had a difference of 4.63 cm, close to statistical significance ($p = 0.084$). For the CMJb (jump with free arms), the difference is 2.46 cm but statistically insignificant ($p = 0.231$). In the squat test, PSW achieved a difference of 1.81 kg more, but without statistical significance ($p = 0.789$).

Table 2 presents the results of specific fitness tests for high-performance handball players (HPHP) and those specialized in the winger position (PSW). The analysis of the results is based on the mean, standard deviation (SD), coefficient of variation (CV), confidence limits and p-values obtained from the t-test.

In Test 1 (Triangle Movement, seconds), HPHP and PSW achieved very close average values, with a difference of only 0.08 seconds. The lower coefficient of variation for HPHP indicates reduced variability. The difference between groups is not statistically significant ($p = 0.826$), suggesting similar performances between the two groups.

In Test 2 (30 m Sprint, seconds), HPHP had a slightly better performance, with a difference of 0.07 seconds compared to PSW. However, the much lower coefficient of variation for PSW highlights greater consistency in the performances of this group. The difference between groups is not statistically significant ($p = 0.404$), showing that the results are similar.

In Test 3 (Handball Throwing for Distance, meters), PSW got a higher average value by 2.47 meters compared to HPHP, but the difference is not statistically significant ($p = 0.147$). The higher coefficient of variation for PSW indicates greater variability in performances for this test.

In conclusion, the differences between high-performance handball players (HPHP) and those specialized in the winger position (PSW) in the technical fitness tests are not statistically significant in any of the three tests. In Test 1 and Test 2, HPHP showed slightly better performance and lower variability, while in Test 3, PSW had a higher average score, but without statistical significance.

Figure 1 demonstrates how strength levels in the lower limbs influence performance in various motor activities. Figure 2 presents the relationship between lower limb strength indices and specific motor tests in handball players specialized in the winger position. Test 1 highlights significant negative correlations for all strength exercises, with the most pronounced ones for CMJ (-0.927) and CMJb (-0.792). These values indicate that better performance in these strength exercises is associated with poorer results in Test 1. The values highlight a strong inverse relationship between explosive strength and technical performance in this test. Test 2 shows strongly positive correlations, especially for squats (0.870) and CMJb (0.378), while CMJ displays a moderate positive correlation (0.258). These results demonstrate that an increase in performance in these strength exercises is associated with improved performance in Test 2. Test 3 has very strong positive correlations, particularly for CMJb (0.923) and squats (0.895). This underlines a close relationship between the strength developed through these exercises and improved performance in Test 3.

In conclusion, squats and CMJb exhibit a more consistent positive correlation with performances in Tests 2 and 3. One the other hand, the CMJ and squat jumps show more pronounced negative correlations, especially in Test 1. These observations suggest that the type and nature of strength exercises can differentially influence the motor performances of handball players in the winger position.

Table 2. Results of specific fitness tests for technical training in elite handball players and the ones specialized in the position of winger

Variables		Mean ± SD	CV (%)	Confidence Level of Mean (0.95)	Confidence Limit of Mean		t	Pvalue
					Lower	Upper		
Test 1	HPHP	11.69 0.56	4.83	0.30	11.39	1.47	0.22	0.826
	PSW	11.61 0.85	7.35	1.36	10.25	12.97		
Test 2	HPHP	4.51 0.16	3.65	0.09	4.42	4.60	0.85	0.404
	PSW	4.44 0.05	1.09	0.07	4.36	4.52		
Test 3	HPHP	49.03 2.76	5.63	1.47	47.56	50.50	-1.52	0.147
	PSW	51.5 3.58	6.96	5.70	45.79	57.20		

Values are expressed as Mean ± Standard Deviations (SD), CV – coefficient of variation; parametric t-Test (Assuming Equal Variances) Unpaired Comparison for Means; HPHP (n=16) – high-performance handball players; PSW(n=4) - players specialized in the position of winger; df = 18; t (0.05) = 2.101

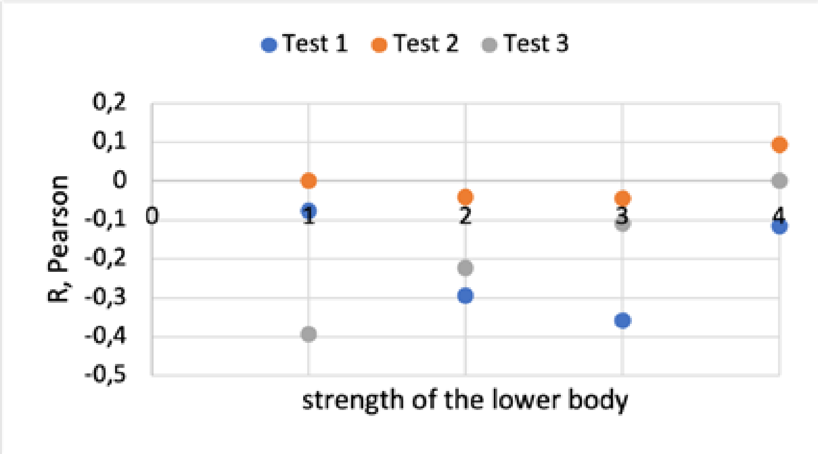

Figure 1. Relationship of lower limbs strength indices and specific motor tests in elite handball players

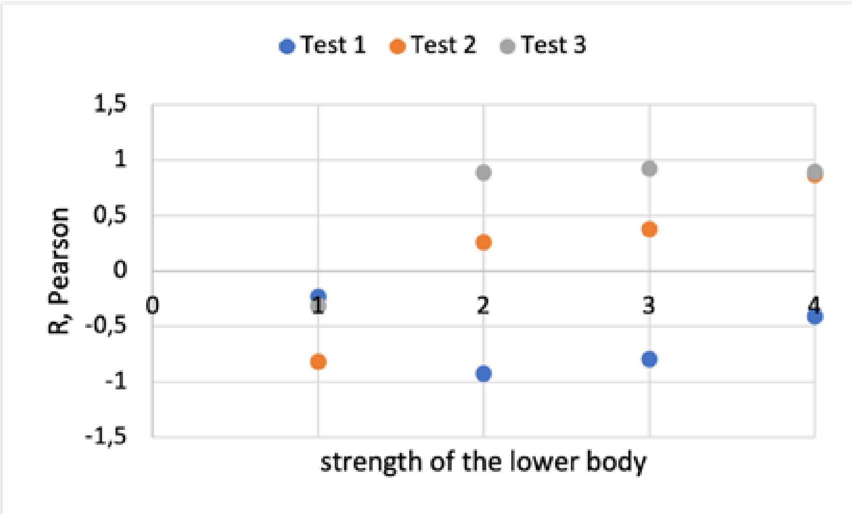

Figure 2. Relationship between lower limbs strength indices and specific motor tests in handball players specialized in the winger position

Discussion

The main objective of the study was to analyze the relationship between upper body speed capacity and lower body strength in elite handball players specialized in the winger position.

The results in Table 1 point out statistically insignificant differences between high-performance handball players (HPHP) and those specialized in the winger position (PSW) concerning lower limb strength. This aligns with research in the specialized literature [1, 5, 18, 19, 20]. It was highlighted that wingers may have slightly different physical requirements, due to their specific playing position. Even so, the differences in explosive strength and jump capacity between positions are not always statistically significant. They prove a similar general physical training at the elite level.

The results in Table 2 indicate statistically insignificant differences between high-performance handball players (HPHP) and those specialized in the winger position (PSW) in technical fitness tests. This fact confirms the specialized literature [13, 21, 22] that emphasizes that performance differences between positions in handball can be minimal in terms of basic training. However, variations in the consistency of results, highlighted by the coefficient of variation, may reflect specific differences in positional requirements and individual playing styles.

Comparative analysis of the results shows that most correlations are negative or insignificant in high-performance handball players in general (Figure 1). As for wingers (Figure 2), exercises like squats and CMJb have a significant positive influence on technical performances, especially in Tests 2 and 3. This suggests that wingers benefit more from training focused on dynamic strength and stability. The exercises focused on explosive strength, such as squat jumps and CMJ, contribute less to developing the technical skills necessary for this position.

The results of this study align with previous literature [23, 24, 25] highlighting the importance of specificity in the physical training of athletes. This specificity depends on the position on the playing field and the specific technical requirements of each position. In particular, studies concerning wingers in team sports like handball have shown that they require a balance between speed, agility, and strength, with emphasis placed on quick lateral movements and short accelerations. Previous research indicates that explosive strength, measured through vertical jump tests such as CMJ and squat jumps, is less relevant for players requiring lateral agility and quick acceleration, such as wingers. Instead, isometric strength and exercises that develop stability and control of lateral movements, such as squats, are associated with better technical performance. In contrast, recent studies have highlighted the importance of monitoring internal and external physical loads in elite young handball players. The studies emphasized the role of game-based training and intermittent recovery tests in optimizing performance and assessing physiological and psychometric responses [9, 10, 11]. The specialists demonstrated a close relationship between the strength and power of upper and lower limbs and the throwing speed in elite handball players. They revealed the importance of specific resistance training in improving physical performance and throwing accuracy [3, 12, 13, 14]. Research indicates that the physical and physiological demands of elite handball involve advanced development of muscle strength and power and also specific adaptation to repeated high-intensity efforts. These are essential aspects for improving overall performance and throwing speed [5, 15, 16, 17]. The studies about athletic training in young athletes emphasize the importance of early development of fundamental physical qualities, like strength and speed. These ones directly influence performance in sports like handball, so a comprehensive and analytical approach is necessary to monitor and optimize their progress [26, 27, 28].

Studies demonstrate that maximal strength training and power-based training play an essential role in increasing throwing speed and muscle strength in handball players. However, there are significant variations depending on playing position and training method used [29, 30, 31]. Other specialists concluded too that the specific physiological and biomechanical demands in elite handball vary significantly depending on playing position and competitive level. The physical performance of players is directly influenced by these variations [21, 32]. Additionally, it has been observed that different team positions, such as the winger, require a distinct movement profile and physical capacity tailored to the specific demands of the game [14, 33]. Research suggests that individual and team performance in handball is considerably influenced by playing position and the level of specific physical training [34, 35, 36]. A similar conclusion is reached by other specialists: physiological characteristics and physical requirements, such as speed and throwing strength, vary according to playing position. For example, wingers and players in other positions have distinct performance profiles [7, 15]. Analyzing movement time and heart rate in elite players of handball beach highlights differences between male and female performances. These are influenced by the specific demands of the game and the environment [37]. Physical fitness profiles in elite beach handball players, regardless of age category, reflect intense specific training, with variations according to age and playing position [38]. Studies conducted by Michalsiket al. [39] provide a detailed analysis of the physical and technical demands in elite handball, focusing on both male and female players. These studies deal with essential aspects such as locomotion characteristics, match-induced fatigue, physiological capacities and the influence of body composition on performance. Therefore, these studies too contribute to the optimization of training strategies and performance of elite handball players [39].

Despite the valuable insights provided by this study, several limitations should be considered. First, the sample size was relatively small, with only 16 elite handball players, which may limit the generalizability of the findings to the broader population of players. Additionally, the study focused specifically on wingers, which may not fully capture the variations in physical capacities and training needs across other playing positions. The cross-sectional design of the study also limits our ability to assess the long-term effects of different training approaches on performance. Future research with a larger sample size, including players from various positions and a longitudinal approach, would help to better understand the impact of tailored training programs on handball performance.

The results of our study indicate the need for tailored training approaches for elite handball players, particularly those in the winger position. The findings show that basic physical capacities, such as lower limb strength and technical fitness, do not significantly differ between wingers and other high-performance players. However, specific exercises like squats and CMJb provide clear benefits for wingers. These findings suggest that training should focus on dynamic strength and stability. Our study aligns with previous research that emphasizes the role of positional specificity in optimizing physical performance. This approach can help refine training programs and ensure that each player's unique demands are met.

Conclusions

The level of lower body strength among high-performance handball players, including those specialized in the winger position, does not present statistically significant differences. This indicates that overall physical conditioning is comparable at the elite level, regardless of positional specialization.

It highlights the role of fundamental training in developing similar strength capacities among players, emphasizing the importance of a solid physical training foundation for all elite athletes. The variations in the consistency of results likely reflect individual playing styles and the specific demands of each position, without significantly affecting overall strength levels.

The findings also suggest a meaningful correlation between training focused on dynamic strength and stability, such as squats and CMJb, and improved technical performance in the game. This improvement is particularly evident in aspects like speed and execution efficiency. These results demonstrate that targeted development of lower body strength can positively impact upper body speed capacity. Thus, the value of an integrated training approach that aligns physical conditioning with the technical demands of handball is underscored. Conversely, exercises aimed at developing explosive strength, like squat jumps and CMJ, appear to play a smaller role in enhancing the technical skills necessary for wingers.

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Conflict of interest

There are no conflicts of interest to declare.

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ORIGINAL ARTICLE

Enhancing respiratory function through Yoga and Pilates in women aged 45-50

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Abstract

Background and Study Aim Respiratory function in women aged 45-50 often declines due to natural physiological changes associated with aging. These changes include reduced lung elasticity, decreased diaphragm efficiency, and a general reduction in physical activity. The purpose of this study was to assess the impact of a combined yoga and Pilates program on respiratory function in women aged 45-50.

Material and Methods The study involved 38 women with an average age of 47.7 ± 2.5 years. A pedagogical experiment was conducted over six months. The experimental group (n=19) participated in a training regimen focused on improving respiratory function through a combination of yoga and Pilates. The control group (n=19) followed a yoga-based training program. Both groups completed an equal number of sessions—72 in total. The external respiratory function of the participants was assessed using spirometry at two key points: at the beginning of the study and after six months.

Results The comparison of respiratory function indicators between the experimental and control groups after 6 months of training revealed significant differences across most parameters. The actual value of Vital Capacity was significantly greater in the experimental group compared to the control group by 0.17 L ($p < 0.01$), forced vital capacity by 0.30 L ($p < 0.01$), forced expiratory volume by 0.19 L ($p < 0.01$), peak expiratory flow by 0.23 L/sec ($p < 0.01$), maximum expiratory flow at 25% of Forced Vital Capacity by 0.96 L/sec ($p < 0.001$), maximum expiratory flow at 50% of Forced Vital Capacity by 0.59 L/sec ($p < 0.001$), expiratory reserve volume by 0.47 L ($p < 0.001$), and maximal voluntary ventilation by 17.00 L/min ($p < 0.001$).

Conclusions The combined Yoga and Pilates training regimen was more effective in improving external respiratory function than Yoga alone. This result highlights the benefits of an integrated approach to respiratory health for women aged 45-50. The study demonstrates the potential advantages of combining different types of exercise to counteract age-related declines in respiratory function. Such programs could play a significant role in promoting overall well-being in this age group.

Keywords: respiratory impairments, functional state, respiratory function, preventive training

Introduction

Respiratory function in women aged 45-50 often declines due to natural physiological changes associated with aging. These changes include reduced lung elasticity, decreased diaphragm efficiency, and a general reduction in physical activity. Lifestyle factors can further worsen this decline. Sedentary behavior and the onset of menopausal symptoms may contribute to respiratory issues and a decrease in overall quality of life.

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Modern research shows that aging is linked to decreased lung capacity, reduced chest wall compliance, and weaker respiratory muscles. These changes result in diminished oxygen intake and a higher risk of respiratory conditions [1, 2]. This problem is especially evident in women going through menopause. Hormonal changes during this period can intensify respiratory challenges, further impacting their health and well-being [3, 4, 5].

Yoga and Pilates have emerged as effective interventions for enhancing respiratory function. They are particularly beneficial due to their emphasis on breath control, posture, and core stability [6]. Recent research has highlighted the potential of mindbody practices, such as yoga and Pilates, to improve respiratory function through controlled breathing, core strengthening, and flexibility exercises [7]. Yoga incorporates pranayama (breathing exercises) that directly target respiratory efficiency. In contrast, Pilates focuses on core stability and posture, which indirectly supports better respiratory mechanics. Studies have shown that regular practice of pranayama can significantly improve lung capacity, respiratory endurance, and overall breathing efficiency [8, 9]. Pilates, with its focus on controlled movements, posture alignment, and diaphragmatic breathing, can enhance respiratory mechanics by strengthening the respiratory muscles [10]. Additionally, Pilates has been shown to increase thoracic mobility and improve diaphragm efficiency, leading to better oxygenation and reduced respiratory effort during physical activity [11].

The Pilates method is widely used in health clinics, where professionals employ it to support voluntary control of heart rate variability, enhance body control, improve posture, and stabilize core muscles during dynamic activities. It also contributes to overall physical and mental well-being [12, 13]. Although Pilates is commonly practiced for managing various conditions [14, 15, 16], its full potential and applications remain somewhat unclear. Both Yoga and Pilates generally offer a holistic approach that integrates physical, mental, and emotional well-being, making them especially beneficial for this demographic [17, 18].

Despite the recognized potential of these practices, there is a noticeable gap in the literature specifically examining the combined effects of yoga and Pilates on respiratory function in women aged 45-50. Most existing studies focus on the impact of these practices individually, yet the synergy between yoga's emphasis on breathing exercises and Pilates' focus on core strength and posture may offer unique benefits. This lack of research leaves an important question unanswered: could a combined approach provide superior improvements in respiratory function compared to each practice alone? Addressing this gap is crucial for developing more effective intervention programs that can better support the respiratory health and overall well-being of women in this demographic.

The hypothesis of this study is that a combined regimen of Yoga and Pilates training over a six-month period will lead to greater improvements in respiratory function compared to a regimen of Yoga alone in women aged 45-50 years.

The purpose of this study was to assess the impact of a combined yoga and Pilates program on respiratory function in women aged 45-50.

Materials and Methods

Participants

The study involved 38 women who participated in a pedagogical experiment conducted over six months. The average age of the participants was 47.7 ± 2.5 years. The experimental group consisted of 19 women who followed a training regimen aimed at improving respiratory function (Yoga+Pilates group). The control group also included 19 women who participated in a yoga-based training program. Both groups attended an equal number of sessions: 72 classes for the combined Yoga and Pilates program in the experimental group and 72 classes for yoga in the control group. All participants provided written informed consent after being thoroughly briefed on the study's purpose, procedures, and their right to withdraw at any time. The study received approval from the Bioethics Committee for Clinical Research and adhered to the principles of the Declaration of Helsinki.

Research Design

The pedagogical experiment was conducted over six months. Both the experimental and control groups received identical training in general and specific physical fitness. The key difference was the inclusion of combined yoga and Pilates exercises in the experimental group. These exercises were individually tailored based on the participants' specific needs and the functional state of their respiratory systems. The program design considered the initial functional capabilities of the participants, allowing for adjustments in the volume and intensity of physical activities. To improve the functional condition of the autonomic nervous system in the experimental group, the program incorporated specialized Pilates exercises and regulated breathing techniques. These were aimed at balancing the parasympathetic and sympathetic nervous systems. The selection of exercises was specifically tailored to address participants' tendencies toward either obstructive or restrictive respiratory impairments.

The combined yoga and Pilates sessions were conducted three times a week for one hour over a three-month period. Each session was structured into three parts: a preparatory phase (10 minutes), a main phase (40 minutes), and a final phase (10 minutes). The intensity of the exercises was progressively increased from 40-45% to 60-70% of the reserve heart rate, adjusted to match the participants' functional capabilities.

The preparatory phase aimed to prepare the respiratory system and muscles for the main exercises, focusing on enhancing lung capacity and control over breathing. The exercises included Tadasana with arm circles, performed slowly to foster a deep connection between breath and movement, with an emphasis on prolonged exhalation. The Pilates shoulder bridge was also used, engaging the core muscles while emphasizing controlled breathing. Additionally, Surya Namaskar served as a gentle flow that warmed up the body and synchronized movement with breath, preparing the respiratory system for more intensive exercises.

The main part combined key elements of Pilates and yoga to enhance external respiratory function through physical and breathing exercises. The exercises included:

- The Hundred: Engaged the deep stabilizing muscles of the core while focusing on deep, rhythmic breathing.
- Single-Leg Stretch: Improved coordination of breath with movement and enhanced breath control.
- Virabhadrasana Series: Strengthened the lower body while promoting diaphragmatic breathing.
- Bhujangasana with Spinal Flexion: Opened the chest and improved lung capacity through deep inhalations.
- Spine Twist: Encouraged thoracic mobility and better lung expansion.
- Vrksasana with Arm Lift: Enhanced balance and incorporated slow, deep breathing for better breath control.
- Side-Lying Leg Lift: Focused on stability and breath coordination.

The final part focused on relaxation and breathing exercises tailored to individual needs based on autonomic nervous system activity. The exercises included:

- Alternate Nostril Breathing: Promoted balance between the sympathetic and parasympathetic nervous systems, enhancing respiratory efficiency.
- Supta Baddha Konasana: Relaxed the body and encouraged deep, diaphragmatic breathing.
- Savasana with Guided Breathing: Focused on deep, slow exhalation to promote relaxation and optimize lung function.

For participants showing signs of restrictive impairments, the emphasis was on vigorous inhalations and breath-holding during the inhalation phase to stimulate the respiratory system. For those with obstructive impairments, the focus was on extended, controlled exhalations and breath-holding during exhalation to calm the nervous system and improve breath control.

The program progressively integrated movements and breathing techniques to prevent fatigue and maintain motivation. Each session was designed to harmonize breath with movement, ensuring that every exercise contributed to the overall goal of improving respiratory function. The external respiratory function of the participants was assessed using spirometry at two key points: at the beginning of the study (before the start of the experimental program) and after six months of regular yoga and Pilates sessions. Before performing spirometry, the equipment was calibrated, and standard spirometry instructions were provided to each participant.

The following spirometry parameters were measured using the SpiroCom device (XAI-Medica, Kharkov, Ukraine):

- Vital Capacity (VC): The total volume of air that can be forcibly exhaled after full inhalation.
- Forced Vital Capacity (FVC): The total volume of air that can be forcibly exhaled after full inhalation.
- Forced Expiratory Volume in 1 second (FEV1): The volume of air exhaled in the first second of a forced breath.
- Peak Expiratory Flow (PEF): The maximum speed of exhalation, reflecting the ability of the airways to conduct airflow rapidly.
- Forced Expiratory Flow (FEF25-50%): The average flow rate during the middle half of the FVC maneuver, which is sensitive to changes in the large and medium bronchi.
- Maximum Voluntary Ventilation (MVV): The greatest amount of air that can be inhaled and exhaled within one minute of voluntary effort.
- Inspiratory Reserve Volume (IRV): The additional volume of air that can be inhaled with maximum effort after a normal inhalation.
- Expiratory Reserve Volume (ERV): The additional volume of air that can be exhaled forcefully after the end of a normal exhalation.

After six months of consistent training, a follow-up spirometry test was conducted to evaluate the impact of the integrated yoga and Pilates regimen on the participants' respiratory function.

Statistical Analysis

The analysis of the collected experimental data was performed using Statistica software for Windows (version 10.00). Initially, the data were assessed for normal distribution, homogeneity, and the presence of outliers. The Shapiro-Wilk test was used to verify the normality of the data distribution. This preliminary evaluation was conducted before proceeding with parametric tests for assessing differences. To analyze changes in respiratory parameters within a group from baseline to post-intervention, a paired t-test was applied. For comparing post-intervention heart rate variability parameters between the two groups, independent sample t-tests were used. A p-value of less than 0.05 was considered statistically significant.

Results

This study demonstrated that most respiratory function parameters improved in both groups over the six months of training. The changes in respiratory function parameters for the experimental and control groups are presented in Table 1.

The results presented in Table 1 demonstrate that most lung function indicators in the experimental group improved significantly after six months of combined Yoga and Pilates training

Table 1. Changes in the respiratory function parameters of the experimental and control groups during the study

Indicator, units of measurement		Experimental group (n=19)		P-level	Control group (n=19)		P-level
		Beginning	6 months		Beginning	6 months	
Vital capacity, l	Actual	2.61±0.08	2.88±0.16**	<0.001	2.59±0.13	2.71±0.17	<0.01
	% of predicted	78.68±4.10	92.26±5.66	<0.001	78.33±3.97	87.22±6.59	<0.01
Forced vital capacity, l	Actual	2.38±0.09	2.74±0.21**	<0.001	2.39±0.10	2.44±0.29	>0.05
	% of predicted	79.99±2.88	87.44±3.69	<0.001	80.01±2.78	82.44±3.55	>0.05
Forced expiratory volume in 1 second, l	Actual	2.07±0.09	2.29±0.14**	<0.001	2.07±0.09	2.10±0.16	>0.05
	% of predicted	83.38±4.29	92.77±5.64*	<0.001	83.38±5.29	84.77±6.54	>0.05
Peak expiratory flow, l/sec	Actual	3.27±0.29	4.82±0.32**	<0.001	3.27±0.35	3.99±0.33	<0.001
	% of predicted	57.88±6.61	72.77±7.28*	<0.001	57.88±1.61	66.78±2.17	<0.05
Maximum expiratory flow 25, l/sec	Actual	2.90±0.08	3.91±0.17***	<0.001	2.90±0.08	2.95±0.18	>0.05
	% of predicted	56.52±4.58	74.87±5.42***	<0.001	56.52±5.58	58.86±6,14	>0.05
Maximum expiratory flow 50, l/sec	Actual	2.83±0.17	3.48±0.21***	<0.001	2.83±0.19	2.89±0.23	>0.05
	% of predicted	79.20±6.25	95.96±7.31***	<0.001	79.20±7.25	81.96±9.84	>0.05
Inspiratory reserve, volume, l		1.12±0.13	1.23±0.29	>0.05	1.12±0.13	1.35±0.28	<0.05
Expiratory reserve volume, l		0.70±0.13	1.30±0.29***	<0.001	0.70±0.14	0.83±0.22	>0.05
Maximal voluntary ventilation, l/min		58.86±6.52	81.59±9.94***	<0.001	58.86±6.63	64.59±7.36	>0.05

Notes: Values are expressed as means ± standard deviations. *p<0.05, **p<0.01, ***p<0.001 compared with the data of the experimental group and the control group after 6 months

compared to baseline. Key improvements included significant increases in vital capacity, forced vital capacity, and forced expiratory volume in 1 second (all $p < 0.001$). Additionally, peak expiratory flow, maximum expiratory flow at 25% and 50% of FVC, and maximal voluntary ventilation also showed substantial gains (all $p < 0.001$). These results indicate a marked improvement in lung function following the combined Yoga and Pilates training regimen in the experimental group. The control group also showed improvements in lung function indicators after six months. However, these changes were generally less pronounced than those observed in the experimental group.

The comparison of respiratory function indicators between the experimental and control groups after six months of training revealed significant differences across most parameters. The actual value of vital capacity (VC) was significantly greater in the experimental group compared to the control group ($p < 0.01$). Similar improvements were observed in forced vital capacity ($p < 0.01$), forced expiratory volume ($p < 0.01$), and peak expiratory flow ($p < 0.01$). Additionally, the experimental group showed significant increases in maximum expiratory flow at 25% ($p < 0.001$) and 50% ($p < 0.001$) of FVC, as well as in expiratory reserve volume ($p < 0.001$) and maximal voluntary ventilation ($p < 0.001$).

Overall, the experimental group, which combined Yoga and Pilates training, showed greater improvements in most respiratory function indicators compared to the control group, which focused solely on yoga. The only exception was inspiratory reserve volume, which was higher in the control group participants. The data reveal statistically significant improvements in the experimental group across key respiratory metrics, including vital capacity (VC), forced vital capacity (FVC), and forced expiratory volume in one second (FEV1).

Discussion

The purpose of this study was to assess the impact of a combined yoga and Pilates program on respiratory function in women aged 45-50. The results demonstrated that this combined training regimen led to more significant improvements in various respiratory function indicators compared to a Yoga-only program. Specifically, the experimental group showed notable improvements in vital capacity, forced vital capacity, forced expiratory volume in 1 second, peak expiratory flow, maximum expiratory flow at 25% and 50% of FVC, expiratory reserve volume, and maximal voluntary ventilation after six months of training. The only indicator where the control group showed a better outcome was inspiratory reserve volume; however, this difference was not statistically significant.

These findings align with previous research that has highlighted the benefits of Pilates and Yoga on respiratory function [19, 20, 21]. However, they provide new insights into the combined effects of these two practices. While Kaminsky et al. [22] observed benefits from Yoga breathing alone, our findings suggest that integrating Pilates, which emphasizes core strength and controlled breathing, can further enhance respiratory function beyond the improvements seen with Yoga alone. Similarly, a study by Cowen and Adams [8] found that Yoga improved lung function, particularly in enhancing FVC and PEF. However, it did not significantly affect FEV1 or MVV, suggesting that Yoga alone might not fully optimize all aspects of respiratory function. Our results indicate that the synergistic effects of Yoga and Pilates may stem from the combination of core stability and respiratory control. Together, these elements enhance overall lung function more effectively.

It should be noted that our study adds to existing research by demonstrating a significant improvement in maximal voluntary ventilation (MVV) in the experimental group. This finding is not as pronounced in previous studies that focused solely on either Pilates or Yoga. In this context, MVV is a critical indicator of respiratory muscle endurance and overall lung function. The results suggest that the combination of Yoga and Pilates may have a synergistic effect, enhancing respiratory endurance more effectively than either practice alone. For women aged 45-50, a combined training regimen may address respiratory limitations more comprehensively than single-modality interventions.

Another contribution of our research is the significant increase in expiratory reserve volume in the experimental group. This result suggests that the combined Yoga and Pilates regimen may enhance the strength and flexibility of the respiratory muscles more effectively than Yoga alone. These findings align with prior research emphasizing the role of muscle flexibility and strength in optimizing respiratory function [23]. However, unlike some studies that primarily focused on FVC or PEF [19, 20], our study offers a broader perspective by highlighting the importance of multiple respiratory indicators.

This study has several limitations that should be acknowledged. First, the sample size was relatively small, with only 38 participants, which may limit the generalizability of the findings to a broader population. Second, the study focused exclusively on women aged 45-50, so the findings may not apply to other age groups or to men. Additionally, the participants were all healthy individuals without underlying respiratory conditions, meaning the results might differ for populations with pre-existing respiratory issues. Finally, while the study used standard spirometry measures to assess respiratory function, it did not explore other potential benefits of the intervention, such as changes in overall physical fitness, psychological well-being, or quality of life. Future research should include a more comprehensive assessment of these factors to fully understand the impact of combined Yoga and Pilates training.

Conclusions

This study demonstrated that a combined Yoga and Pilates program leads to significant improvements in respiratory function in women aged 45-50, surpassing a Yoga-only program in most parameters. Key improvements were observed in vital capacity (VC), forced vital capacity (FVC), forced expiratory volume (FEV1), and peak expiratory flow (PEF). These findings support the hypothesis that integrating Pilates with Yoga provides greater benefits for respiratory health than practicing Yoga alone.

Conflicts of interest

Author declares that there is no conflict of interests.

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ORIGINAL ARTICLE

The effects of hybrid physical activity program on various motor skills in primary school children

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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	Physical activity in children is fundamental to the development of motor skills. Despite its importance, physical activity programs do not fully address the needs of this age group. This study examined the effects of a hybrid physical activity program on specific motor skills in primary school children.
Material and Methods	A quantitative single-group pretest-posttest model was used in this study. The research group included 34 voluntary students, with 19 boys and 15 girls, all in the 3rd and 4th grades of primary school. Participants followed a hybrid physical activity program developed by the researcher. The program lasted for 8 weeks, with sessions conducted 3 days a week face-to-face and 4 days a week at home. Home sessions involved parental support through the Moodle system, using educational videos or visual games. Each session lasted one hour and was supervised by an expert trainer. Motor competence data were collected using the second version of the "Test of Gross Motor Development-2" (TGMD-2), known for its reliability and validity. The data were analyzed using the SPSS 26.0 statistical package, with a significance level set at p<0.05.
Results	The study's findings showed significant differences in some sub-skills and total raw scores of the locomotor and object control tests between boys and girls ($p < 0.05$). Significant differences were also found between the 8- and 9-year-old groups in sub-skills and total raw scores ($p < 0.05$). Additionally, a significant difference was observed in certain sub-skills and total raw score assessments between the 3rd and 4th grades ($p < 0.05$).
Conclusions	The hybrid physical activity program proved to be an effective approach for enhancing motor skills in primary school children. The findings highlight the importance of tailored physical activity programs that consider individual characteristics such as age, gender, and grade level. Implementing such programs in both school and home settings can promote more comprehensive motor development in children.

Keywords: hybrid model, physical activity, exercise, motor skills, TGMD-2

Introduction

The primary school age is a crucial period for children's growth and development, as it lays the foundation for acquiring skills essential for becoming healthy individuals. During this phase, children benefit greatly from diverse stimuli that foster their cognitive, sensory, social, and physical growth [1]. Physical activity and technological advancements are particularly engaging to primary school children, offering experiences that support their overall development.

Engaging in physical activity from an early age supports neuromuscular development and contributes to the development of motor skills, while also reducing sedentary behaviors and promoting an active lifestyle [2, 3, 4, 5, 6]. Regular participation in physical activity plays a protective role against many chronic conditions, particularly obesity, in children [7, 8, 9]. Additionally, regular exercise aids in healthy growth and bone development, enhances cardiovascular health, supports psychosocial well-being, and assists in weight control in children [10]. It is thus evident that one of the most crucial factors in maintaining weight control is the productive use of free time through physical activity [11, 12]. Leisure time activities are an important concept that directly influences an individual's happiness, quality of life, and overall health [13, 14]. Therefore, increasing opportunities for leisure-based activities and utilizing them effectively can enable children to engage in regular physical activities, ultimately leading to a healthier lifestyle [15].

Technological advancements have become a significant aspect of human life, influencing nearly all areas of life [16, 17]. The rapid advancements in technology since the late 20th century have been particularly evident in the field of education [18]. This acceleration has led to the emergence of hybrid learning models, which have become

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integral to modern education. Hybrid learning is a blend of face-to-face and online learning methods [19], combining various learning resources through technological tools such as TVs, computers, phones, and presentations, offering students opportunities for lifelong learning and development [20]. It can be applied across diverse learning environments and provides flexibility, allowing for the creation of varied educational settings and maximizing the use of available resources. Additionally, it empowers students to tailor their learning processes according to their individual characteristics and needs [21].

Hybrid learning and education models are not limited to specific scientific disciplines but are also applied in sports sciences. In the field of physical education and sports, especially concerning physical activity and exercise, hybrid learning supports the processes of learning and applying movements [22]. Additionally, technology-driven hybrid activities enhance children's and young people's interest and participation in physical activity, offering opportunities for increased motivation, social interaction, accessibility, and equality [23, 24].

Despite the numerous studies emphasizing the importance of physical activity and hybrid learning models in supporting children's development, there remains a need for more effective solutions to address these challenges. Current approaches have made significant progress in promoting active lifestyles and incorporating technological advancements into education. However, identifying the most efficient methods to integrate these elements in a way that maximizes their benefits for primary school children is still a critical area of research.

This research aims to examine the effects of a hybrid physical activity program on specific motor skills in primary school children.

Materials and Methods

A quantitative single-group pretest-posttest model was used in this research. This quantitative research design aims to determine the cause-effect relationship between variables. The single-group pretest-posttest model involves taking measurements before and after the intervention in a randomly selected group [25, 26].

Participants

The research group consisted of 34 students, including 15 third-grade and 19 fourth-grade students from Fatih Primary School in Bartin. Before the study, participants were provided with detailed information about the test protocols and study procedures. Informed consent forms were obtained from the parents of the participants. Ethical approval for the study was granted by the Bartin University Social and Human Sciences Ethics Committee, with the protocol number 2022-SBB-0644. The demographic characteristics of the study participants, including gender, age, grade level, and preferred hand and foot, are summarized in Table 2.

Table 1. Demographic Characteristics of Study Participants

Characteristic	Category	n	%
Gender	Male	19	55.9%
	Female	15	44.1%
Age	8 years old	14	41.2%
	9 years old	18	52.9%
	10 years old	2	5.9%
Grade Level	3rd grade	15	44.1%
	4th grade	19	55.9%
Preferred Hand	Right hand	31	91.2%
	Left hand	3	8.8%
Preferred Foot	Right foot	31	91.2%
	Left foot	3	8.8%

Study Design

The data collection tools included the "Parent Permission Form" for minors, the "Moodle System," and the short form of the "Test of Gross Motor Development-2" (TGMD-2) for assessing motor competence.

Test of Gross Motor Development-2 (TGMD-2) Ulrich developed and revised this test to assess the motor development levels of children aged 3 to 10 years [27, 28]. The TGMD-2 consists of two subtests: locomotor skills and object control skills. Locomotor skills include running, galloping, hopping, leaping, horizontal jumping, and sliding. Object control skills include striking a stationary ball, dribbling, catching, kicking, overhand throwing, and underhand rolling. Each subtest comprises six sub-skills, resulting in a total of 12 sub-skills. Each sub-skill test involves 3 or 5 movement analysis items.

The Turkish adaptation and reliability-validity studies of the TGMD-2 were conducted by Boz [29]. Boz reported Cronbach's Alpha internal consistency coefficients ranging from 0.83 to 0.88 for locomotor skills, 0.75 to 0.82 for object control skills, and 0.88 to 0.92 for the total test. However, in the Turkish validity and reliability study, the "striking a stationary ball" item showed a low correlation (0.19) with the object control subtest. As a result, this item was removed, and the validity and reliability studies were adjusted accordingly [29, 30].

Physical Activity Plan

Participants followed a hybrid physical activity program developed by the researcher (Table 2). The program lasted 8 weeks, with activities conducted 3 days a week face-to-face and 4 days a week at home. Home sessions were supported by parents through the Moodle system using educational videos or visual games. Each session lasted one hour and was supervised by an expert trainer. The hybrid physical

Table 2. Physical activity program for developing fundamental movement skills for 3rd and 4th grade students

Week	Activity Type	Frequency (day)	Time (minute)	Intensity	Targeted Motor Skill for Development
1	Face-to-Face	3	60	Low	Locomotor skills (Walking, Running, Jumping, Hopping, Stepping, Skipping, Sliding, Climbing)
1	Moodle system	4	60	Low	Locomotor skills (Walking, Running, Jumping, Hopping, Stepping, Skipping, Sliding, Climbing)
2	Face-to-Face	3	60	Moderate	Non-Locomotor skills (Bending, Twisting, Swaying, Stretching)
2	Moodle system	4	60	Moderate	Non-Locomotor skills (Bending, Twisting, Swaying, Stretching)
3-4, 5-6	Face-to-Face	3	60	Moderate	Manipulative skills (Holding, Throwing, Catching, Dribbling, Kicking, Controlling)
3-4, 5-6	Moodle system	4	60	Moderate	Manipulative skills (Holding, Throwing, Catching, Dribbling, Kicking, Controlling)
7-8	Face-to-Face	3	60	Moderate	Balance and rhythm skills (Bending, Stretching, Static and Dynamic balance, rhythm)
7-8	Moodle system	4	60	Moderate	Balance and rhythm skills (Bending, Stretching, Static and Dynamic balance, rhythm)

activity plan was designed by expert educators. It considered the developmental characteristics of children and included weekly development goals, such as locomotor, balance, and manipulative skills. The plan combined face-to-face and online (hybrid) activities to achieve these goals.

This structured program gradually introduces different motor skills, allowing students to progress from basic locomotor skills to more complex manipulative and balance skills. The combination of face-to-face and home-based activities provides a balanced approach to motor development, ensuring consistent practice and skill acquisition.

Moodle System

The Moodle system is a free and open-source learning platform based on pedagogical principles, designed to assist educators [31]. Usernames and passwords were created for administrators, parents (as students), and teachers to access the system. Each parent and teacher received a detailed explanation of how to use the Moodle system, including instructions on logging in and conducting physical activities at home. To ensure the continuity of the study, regular checks were performed on parents' system logins. Reminders were sent to those who forgot or did not log in, emphasizing the importance of participating in the activities. Parents who did not regularly log in were excluded from the study. Figure 1 provides an example of a physical activity conducted both face-to-face and through the Moodle system to develop basic motoric features.

Statistical Analysis

The data were analyzed using the SPSS 26.0 statistical package program, with the significance level set at $p<0.05$. To determine whether there were significant differences in the students' motor skill test results before and after the intervention based on different variables, a paired sample t-test was employed. Prior to the test, Skewness and Kurtosis values were examined to verify if the data followed a normal distribution. Values between -2 and +2 indicate that the data are normally distributed [32]. Additionally, the minimum and maximum score values obtained were recorded. Correlation measures the degree of mathematical relationship between two variables [33], with the correlation coefficient (r) ranging between +1 and -1 [34]. Double asterisks indicate a correlation at the 1% significance level, while single asterisks denote a correlation at the 5% significance level.

Results

The results of the study are presented in Tables 3-9. In Table 3, when examining the locomotor sub-skills of participants based on gender, it was found that male participants showed statistically significant differences in running, galloping, jumping over an obstacle, long jumping, and sliding, while female participants showed statistically significant differences in running, hopping, jumping over an obstacle, and sliding ($p<0.05$). No statistically significant differences were found in hopping for male participants and in galloping and long jumping for female participants ($p>0.05$). When examining the object control sub-skills of participants based on gender, it was found that male participants showed statistically significant differences in dribbling, kicking, throwing, and rolling a ball, while female participants showed statistically significant differences in dribbling,

Figure 1. Example Physical Activity in Face-to-Face and Moodle System to Develop Basic Motoric Features

throwing, and rolling a ball (p<0.05). No statistically significant differences were found in catching for male participants and in catching and kicking for female participants (p>0.05).

In Table 4, when examining the total raw scores of participants based on gender, statistically significant differences were found in the pre-test and post-test scores for locomotor skills, object control skills, and the overall Test of Gross Motor Development-2 (TGMD-2) for both male and female participants (p<0.05).

In Table 5, when examining the locomotor sub-skills of participants based on age, it was found that 8-year-old participants showed statistically significant differences in galloping and hopping, while 9-year-old participants showed statistically significant differences in running, jumping over an obstacle, and sliding (p<0.05). No statistically significant differences were found in running, jumping over an obstacle, long jumping, and sliding for 8-year-old participants, and in galloping, hopping, and long jumping for 9-year-old participants. For 10-year-old participants, no statistically significant differences were found in locomotor sub-skills (p>0.05). When examining the object control sub-skills of participants based on age, it was found that 8-year-old participants showed statistically significant differences in dribbling, catching, kicking, throwing, and rolling a ball, while 9-year-old participants showed statistically significant differences in dribbling, throwing, and rolling a ball (p<0.05). No statistically significant differences were found in catching and kicking for 9-year-old participants, and no statistically significant differences were found in object control sub-skills for 10-year-old participants (p>0.05).

In Table 6, when examining the total raw scores of participants based on age, it was found that there were statistically significant differences in the pre-test and post-test scores for locomotor skills, object control skills, and TGMD-2 for 8- and 9-year-old participants (p<0.05). No statistically significant differences were found in the pre-test and post-test scores of sub-skills for 10-year-old participants (p>0.05).

In Table 7, when examining the locomotor

Table 3. T-test Results of Participants' Relocation and Object Control Skill Scores According to the Gender Variable

Sub-skills	Gender	n	Pre-test X±SD	Post-test X±SD	SD	t	p
Running	Male	19	5.316±1.4550	7.053±1.2236	2.130	3.554	0.002*
	Female	15	4.667±1.6330	6.933±1.3345	2.250	3.900	0.002*
Gallop	Male	19	6.316±1.2933	7.421±1.0174	1.822	2.643	0.017*
	Female	15	6.467±0.9904	7.267±1.0328	1.521	2.037	0.061
One-Legged Hop	Male	19	7.632±2.0333	8.368±1.6737	2.256	1.423	0.172
	Female	15	7.933±1.8696	9.000±0.6547	1.667	2.744	0.027*
Running Over Hurdle	Male	19	4.053±1.5802	5.105±1.2425	2.223	2.064	0.54*
	Female	19	4.000±1.3628	5.200±0.8619	1.698	2.736	0.016*
Long Jump	Male	19	5.895±1.7605	7.105±1.1002	2.347	2.248	0.037*
	Female	15	6.067±1.6676	6.200±1.2071	2.231	0.231	0.820
Sliding	Male	19	6.000±1.9149	7.158±0.8983	1.708	2.955	0.008*
	Female	15	5.467±2.1996	6.933±1.0328	2.294	2.475	0.027*
Bouncing the Ball	Male	19	5.895±1.6632	7.526±0.6967	1.605	4.429	0.000*
	Female	15	5.267±1.7512	6.800±1.0142	1.995	2.976	0.010*
Holding the Ball	Male	19	5.053±1.1291	5.211±0.8550	1.463	0.470	0.644
	Female	15	5.533±1.1127	5.533±0.6399	1.014	0.764	0.458
Kicking the Ball	Male	19	6.526±1.3068	7.632±0.5973	1.448	3.325	0.004*
	Female	15	6.467±1.1255	7.000±0.8452	1.060	1.948	0.072
Throwing the Ball	Male	19	6.368±1.7705	7.789±0.4189	1.773	3.492	0.003*
	Female	15	4.800±1.9346	6.933±1.1629	1.807	4.571	0.000*
Rolling the Ball	Male	19	5.632±1.8622	7.158±1.1673	1.836	3.622	0.002*
	Female	15	5.600±1.7238	7.000±1.3628	1.681	3.224	0.006*

Note. * - p<0.05

Table 4. T-test results for participants' raw scores on locomotor-object control skills and total scores on the Test of Gross Motor Development-2 (TGMD-2) by gender variable

Total Raw Score	Gender	n	Pre-test X±SD	Post-test X±SD	SD	t	p
Locomotor raw score	Male	19	35.211±3.7650	42.211±3.5836	5.416	5.634	0.000*
	Female	15	34.600±4.9828	41.533±3.2264	5.020	5.348	0.000*
Object Control Raw Score	Male	19	29.474±3.0252	35.316±1.8575	2.930	8.691	0.000*
	Female	15	26.800±5.3077	33.267±2.9147	4.793	5.224	0.000*
BKMGT-2	Male	19	64.684±1.3313	77.526±4.2865	6.202	9.025	0.000*
	Female	15	62.067±7.6108	74.800±4.9019	5.637	8.748	0.000*

Note. * - p<0.05

sub-skills of participants based on class, it was found that 3rd-grade participants showed statistically significant differences in galloping and hopping, while 4th-grade participants showed statistically significant differences in running, jumping over an obstacle, and sliding (p<0.05). No statistically significant differences were found in running, jumping over an obstacle, long jumping, and sliding for 3rd-grade participants, and no statistically significant differences were found in galloping, hopping, and long jumping for 4th-grade participants (p>0.05). When examining the object control sub-skills of participants based on class, it was found that 3rd-grade participants showed statistically significant differences in dribbling, catching, kicking, throwing, and rolling a ball, while 4th-grade participants showed statistically significant differences in dribbling, throwing, and

Table 5. T-test Results of Participants' Displacement and Object Control Skill Scores According to the Age Variable

Sub-skills	Age	n	Pre-test X±SD	Post-test X±SD	SD	t	p
Running	8	14	5.571±1.5549	6.000±1.3009	1.910	0.840	0.416
	9	18	4.722±1.5265	7.722±0.5745	1.715	7.422	0.000*
	10	2	4.000±0.0000	7.500±0.7071	0.707	7.000	0.090
Gallop	8	14	6.000±1.1094	7.786±0.5789	1.476	4.524	0.001*
	9	18	6.556±1.1490	7.056±1.1618	1.581	1.342	0.197
	10	2	7.500±0.7071	7.000±1.4142	2.121	-.333	0.795
One-Legged Hop	8	14	6.786±1.5281	7.857±1.4064	1.542	2.599	0.022*
	9	18	8.556±1.9470	9.222±1.0603	2.351	1.203	0.246
	10	2	7.500±2.1213	9.000±0.0000	2.121	1.000	0.500
Running Over Hurdle	8	14	4.214±1.2514	4.857±1.1673	1.736	1.385	0.189
	9	18	3.889±1.5676	5.389±0.9785	1.977	3.218	0.005*
	10	2	4.000±2.8284	5.000±1.4142	4.242	0.333	0.795
Long Jump	8	14	5.714±2.0164	6.571±1.5046	2.851	1.125	0.281
	9	18	6.167±1.5049	6.833±1.0432	2.000	1.414	0.175
	10	2	6.000±1.4142	6.500±0.7071	2.121	0.333	0.795
Sliding	8	14	6.500±1.6984	7.286±0.9139	1.528	1.924	0.077
	9	18	5.056±2.1275	6.889±0.9634	2.229	3.489	0.003*
	10	2	7.000±1.4142	7.562±7078	2.122	0.353	0.825
Bouncing the Ball	8	14	6.286±1.5407	7.143±0.9493	1.027	3.122	0.008*
	9	18	5.389±1.5770	7.278±0.8948	1.996	4.014	0.001*
	10	2	3.000±1.4142	7.000±0.0000	1.414	2.000	0.300
Holding the Ball	8	14	4.571±1.2225	5.357±0.6333	1.181	2.474	0.028*
	9	18	5.667±0.7670	5.278±0.8948	1.092	-1.511	0.149
	10	2	5.000±1.4142	6.000±0.0000	1.414	1.000	0.500
Kicking the Ball	8	14	6.214±1.4239	7.429±0.6462	1.423	3.191	0.007*
	9	18	6.833±0.9852	7.222±0.8782	1.036	1.591	0.130
	10	2	5.500±0.7071	8.000±0.0000	0.707	5.000	0.126
Throwing the Ball	8	14	5.429±1.8277	7.071±1.1411	1.691	3.633	0.003*
	9	18	5.667±2.1420	7.611±0.6978	1.954	4.221	0.001*
	10	2	7.500±0.7071	8.000±0.000	0.707	1.000	0.500
Rolling the Ball	8	14	5.429±2.0273	6.571±1.3425	1.915	2.232	0.044*
	9	18	5.667±1.6803	7.389±1.0922	1.708	4.277	0.001*
	10	2	6.500±0.7071	8.000±0.0000	0.707	3.000	0.205

Note. * - p<0.05

rolling a ball (p<0.05). No statistically significant differences were found in catching and kicking for 4th-grade participants (p>0.05).

In Table 8, when examining the total raw scores of participants based on class, it was found that there were statistically significant differences in the pre-test and post-test scores for locomotor skills, object control skills, and TGMD-2 for both 3rd- and 4th-grade participants (p<0.05). In Table 9 a significant relationship was observed between the TGMD-2 pre-test and post-test scores collected from students both before and after the intervention.

Discussion

Our study aimed to predict the findings and compare them with the information in the literature by analyzing the effects of a hybrid physical activity program applied to primary school children on specific motor skills. According to the gender variable, statistically significant differences were

Table 6. T-test results for participants' raw scores on locomotor-object control skills and total scores on the Test of Gross Motor Development-2 (TGMD-2) by age variable

Total Raw Score	Age	n	Pre-test X±SD	Post-test X±SD	SD	t	p
Locomotor raw score	8	14	34.786±5.4091	40.357±3.6712	5.094	4.092	0.001*
	9	18	34.944±3.6051	43.111±2.9082	5.316	6.517	0.000*
	10	2	36.000±1.4142	42.000±1.4142	2.828	3.000	0.205
Object Control Raw Score	8	14	27.214±5.8596	33.571±2.8747	4.684	5.078	0.000*
	9	18	29.222±2.8606	34.778±2.1843	3.072	7.672	0.000*
	10	2	27.500±0.7071	37.500±1.4142	2.121	6.333	0.100
BKMGT-2	8	14	62.714±8.7656	73.929±5.2545	5.577	7.524	0.000*
	9	18	64.167±5.1933	77.889±3.6924	6.266	9.290	0.000*
	10	2	63.500±0.7071	79.000±0.0000	0.707	31.000	0.021

Note. * - p<0.05

Table 7. T-test Results for Participants' Locomotor and Object Control Skill Scores by Grade Variable

Sub-skills	Grade	n	Pre-test X±SD	Post-test X±Sd	SD	t	p
Running	3rd Grade	15	5.400±1.6388	6.067±1.2799	2.058	1.254	0.230
	4th Grade	19	4.737±1.4469	7.737±0.5620	1.666	7.846	0.000*
Gallop	3rd Grade	15	5.933±1.0998	7.733±0.5936	1.424	4.895	0.000*
	4th Grade	19	6.737±1.0976	7.053±1.1773	1.600	0.860	0.401
One-Legged Hop	3rd Grade	15	6.667±1.5430	7.867±1.3558	1.567	2.965	0.010*
	4th Grade	19	8.632±1.8016	9.263±0.9912	2.290	1.202	0.245
Running Over Hurdle	3rd Grade	15	4.333±1.2910	4.733±1.2228	1.919	0.807	0.433
	4th Grade	19	3.789±1.5839	5.474±0.8412	1.887	3.890	0.001*
Long Jump	3rd Grade	15	5.867±2.0307	6.533±1.4573	2.845	0.907	0.380
	4th Grade	19	6.053±1.4327	6.842±1.0145	1.902	1.809	0.087
Sliding	3rd Grade	15	6.600±1.6818	7.333±0.8997	1.486	1.911	0.077
	4th Grade	19	5.105±2.0789	6.842±0.9582	2.207	3.430	0.003*
Bouncing the Ball	3rd Grade	15	6.400±1.5492	7.200±0.9411	1.014	3.055	0.009*
	4th Grade	19	5.000±1.5986	7.211±0.9177	1.988	4.846	0.000*
Holding the Ball	3rd Grade	15	4.667±1.2344	5.333±0.6172	1.234	2.092	0.055*
	4th Grade	19	5.579±0.8377	5.368±0.8951	1.182	-.776	0.448
Kicking the Ball	3rd Grade	15	6.200±1.3732	7.467±0.6399	1.387	3.537	0.003*
	4th Grade	19	6.737±1.0457	7.263±0.8719	1.172	1.957	0.066
Throwing the Ball	3rd Grade	15	5.200±1.9712	7.067±1.0998	1.846	3.915	0.002*
	4th Grade	19	6.053±1.9571	7.684±0.6710	1.801	3.948	0.001*
Rolling the Ball	3rd Grade	15	5.600±2.0633	6.667±1.3452	1.869	2.210	0.044*
	4th Grade	19	5.632±1.5709	7.421±1.0706	1.618	4.819	0.000*

Note. * - p<0.05

found in some sub-skills of the locomotion and object control tests, as well as in the total raw scores of male and female participants when comparing pre-test and post-test results (p<0.05). When the literature is reviewed, a study conducted with 30 male and female students - 16 of whom received traditional education and 14 of whom received Montessori education - implemented a movement and play education program that lasted 45 minutes twice a week for 12 weeks. The results of this study showed that the play education program applied to both groups led to a significant difference in the TGMD-2 locomotor and object control sub-skills scores, resulting in improved motor skills [35].

Table 8. T-test results for participants' raw scores on locomotor-object control skills and total scores on the Test of Gross Motor Development-2 (TGMD-2) by Grade variable

Total Raw Score	Grade	n	Pre-test X±SD	Post-test X±SD	SD	t	p
Locomotor raw score	3rd Grade	15	34.800±5.2126	40.267±3.5550	4.926	4.298	0.001*
	4th Grade	19	35.053±3.5351	43.211±2.6994	5.166	6.882	0.000*
Object Control Raw Score	3rd Grade	15	27.400±5.6921	33.733±2.8402	4.514	5.433	0.000*
	4th Grade	19	29.000±2.8284	34.947±2.2428	3.274	7.918	0.000*
BKMGT-2	3rd Grade	15	62.867±8.4673	74.000±5.0709	5.383	8.010	0.000*
	4th Grade	19	64.053±5.0495	78.158±3.5318	6.045	10.171	0.000*

Note. * - p<0.05

Table 9. Participants' Pearson correlation analysis results

		Pre-test Locomotor Skill	Pre-test Object Control Skill	Pre-test Total	Post-test Locomotor Skill	Post-test Object Control Skill	Post-test Total
Pre-test Locomotor	R	1					
	P						
	N	34					
Pre-test Object Control	R	.537**	1				
	P	.001					
	N	34	34				
Pre-test Total	R	.873**	.842**	1			
	P	.000	.000				
	N	34	34	34			
Post-test Locomotor	R	.110	.482**	.344*	1		
	P	.536	.004	.047			
	N	34	34	34	34		
Pre-test Object Control	R	.364*	.486**	.488**	.231	1	
	P	.034	.004	.003	.189		
	N	34	34	34	34	34	
Post-test Total	R	.278	.613**	.514**	.848**	.711**	1
	P	.112	.000	.002	.000	.000	
	N	34	34	34	34	34	34

Note. * - P<0.05; ** - P<0.01; R - Pearson correlation coefficient; N - sample size

In another study conducted with children with characteristics similar to those of our study group, it was found that the group receiving movement education for 2 hours a week for 14 weeks showed improvements in motor performance and skills [36]. The results of other studies are consistent with our findings [37, 38, 39]. However, the existing literature emphasizes the positive effects of physical activities supported by individual assistance rather than those of technology-supported interventions on motor skills. In this context, our study demonstrates the positive effects of integrating technology support with individual assistance on the development of motor skills.

In another study similar to ours, a study was conducted with 183 primary school students, dividing the participants into three groups: control, information technology-supported movement education, and teacher-supported movement education. The information technology-supported group learned the movements through an information-based system, while the teacher-supported group performed the movements under the guidance of physical education teachers. The TGMD-2 motor test was used before and after the eight-week program, which took place for two hours a week. The results showed positive effects on locomotion, object control, and gross motor development in both the information technology-supported and teacher-supported groups. Gender did not impact motor performance, locomotion, object control, or total scores [40]. Other studies in the literature also demonstrate that gender does not influence motor performance and skills [41, 42, 43]. This discrepancy may be due to differences in the sample groups and the content of the physical activity programs applied.

According to the age variable, statistically significant differences were found in some sub-skills of the locomotion and object control tests, as well as in the total raw scores of 8-9-year-old participants when comparing pre-test and post-test results ($p<0.05$). In a study involving a similar age group, 17 female students participated in a gymnastics training program two days a week, one hour per day, for eight weeks, with motor performance and skills assessed using the TGMD-2 test. The results showed positive improvements in all parameters except locomotor skills in the post-test measurements [44]. In another study, a 12-week coordination-based movement training program was observed to improve motor performance [45]. A similar study in the literature involved 906 preschool children - 662 Turkish and 244 Bulgarian - using the Ulrich Gross Motor Development Test. This study applied video-based digital physical exercise videos for 15 minutes over eight weeks, and the results indicated that the digital exercise program significantly improved gross motor skills in the experimental group [46].

In addition, other studies in the literature align with our findings. Regularly performed fundamental movement training and gymnastics education in children have been shown to positively support the development of motor skills [47, 48, 49, 50]. Similarly, it has been reported that educational game-based training has positive effects on the subcomponents of motor skills in children [51, 52, 53]. Furthermore, another study found that a video game-supported model contributed to the motor development of children [54]. In other studies, it has been determined that physical activity conducted for a duration of 3 months supports motor development in children [55, 56, 57]. Other studies have indicated that motor skill training and structured games enhance children's motor and movement development [58, 59]. Additionally, a study found that the motor skills of children who engage in sports differ from those who do not, with children participating in sports showing better motor skills [60]. Some studies have also found that specially designed developmental training and multidimensional exercise plans for children positively impact motor development [61, 62, 63, 64].

According to the grade variable, statistically significant differences were found in some sub-skills of the locomotion and object control tests, as well as in the total raw scores of 3rd- and 4th-grade participants when comparing pre-test and post-test results ($p<0.05$). In a study from the literature involving 54 children in 1st, 2nd, 3rd, and 4th grades, physical activity using physical activity cards (PAC) was implemented three days a week for eight weeks, followed by height and weight measurements of both groups, and the TGMD-2 test was applied. The results indicated positive effects on movement, object control, and gross motor development in the experimental group [65]. Similarly, in a study conducted with a total of 40 4th-grade students in experimental and control groups, futsal training was added to the Ministry of National Education curriculum for motor skills training and implemented for eight weeks. The TGMD-3 test was used for pre- and post-program measurements. The results showed that the training program applied to the experimental group improved locomotor skills, ball skills, and gross motor skills [66]. The results of other studies in the literature are consistent with our findings [67, 68, 69].

The findings of our study indicate that a hybrid physical activity program positively influences the development of motor skills in primary school children. The observed improvements in locomotor and object control skills align with existing literature. This supports the effectiveness of both traditional and technology-supported programs. However, our study has certain limitations. These include a relatively small sample size and a short duration of the intervention. Future research should consider using larger and more diverse samples. Additionally, it is important to investigate how different components of these programs can be optimized to further enhance motor development in children.

Conclusions

The hybrid physical activity program applied in this study improved certain motor skills in children. Unlike traditional methods, hybrid activities can stimulate curiosity in children, fostering motivation and the development of regular physical activity habits. Additionally, hybrid programs help reduce inequalities in access to physical activities, strengthen family bonds, and encourage parental involvement in their children's physical activities. They also support the development of children's social skills, making hybrid approaches a valuable addition to traditional physical education methods.

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