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[Teorìâ ta Metodika Fìzičnogo Vihovannâ]

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Original Scientific Article

Considering the Impact of a Tactical and Technical Training Module on the Performance of Field Hockey Players (U-16) in Malaysia: A Quasi-Experimental Design

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

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Abstract

Background. The development of tactical and technical skills is critical for young athletes engaged in team sports, particularly in field hockey, where quick decision-making and strategic play are essential for success.

Objectives. This study aimed to evaluate the effectiveness of a structured tactical and technical training module on the performance of field hockey players (U-16) in Malaysia.

Materials and methods. A quasi-experimental design was used, involving 40 participants who were randomly assigned to either an intervention group (n = 20) or a control group (n = 20). The intervention group underwent an eight-week tactical and technical training module, while the control group followed their regular training regimen. Pre-test and post-test assessments were conducted to measure knowledge and performance in four key areas: ball action/direction, opponents' action, positioning, and action during changing situations. The data were analyzed using Multivariate Analysis of Variance (MANOVA) to assess the impact of the intervention.

Results. The MANOVA results revealed significant improvements in the intervention group across all four variables compared to the control group (Wilks' Lambda = 0.327, F = 9.867, p = 0.001). Specifically, the intervention group showed substantial gains in knowledge about ball action/direction, opponents' action, positioning, and actions during changing situations. These findings underscore the effectiveness of the training module in enhancing tactical and technical competencies in young field hockey players. The study demonstrates that a structured tactical and technical training module can significantly improve the performance of under-16 field hockey players.

Conclusions. The results indicate the potential for broader application of such modules in youth sports development programs. It is recommended that coaches integrate similar training structures to optimize player development and competitive performance.

Keywords: field hockey, tactical training, technical skills, youth sports, performance enhancement, Malaysia.

Introduction

Field hockey is a highly competitive and physically demanding sport that requires players to exhibit a high level of skill, agility, and strategic thinking (Osman et al., 2020). Over the years, the sport has evolved significantly, with increased emphasis on both technical and tactical competencies that enable players to perform optimally in high-pressure situations (Timmerman et al., 2019). Technical skills in field hockey refer to the fundamental abilities such as dribbling, passing, and shooting, which are essential for executing game strategies effectively (Kostiukevych et al., 2021; Manaf et al., 2021; Hasnor et al., 2018). Tactical skills, on the other hand, involve the strategic use of these techniques to outmaneuver opponents, make quick decisions, and adapt to the dynamic nature of the game (Lord et al., 2022).

In Malaysia, field hockey has a rich history and is considered one of the more popular sports, with a strong

tradition of participation at both the youth and professional levels (Khan et al., 2023). However, despite the country's enthusiasm for the sport, there remains a pressing need to improve the technical and tactical training provided to young players, particularly those in the under-16 category. The performance of these players is often hindered by inadequate training modules that fail to integrate both technical and tactical elements effectively, leading to a gap between Malaysian players and their international counterparts (Nathan, 2019; Tajudin et al., 2022). The importance of developing a module that addresses both tactical and technical aspects of field hockey cannot be overstated. Such a module is crucial for the holistic development of young players, equipping them with the necessary skills to compete at higher levels. The integration of technical and tactical training in a single module can lead to significant improvements in players' performance, as it allows for the practical application of technical skills within a tactical framework (Tallah, 2016). This approach is particularly relevant for under-16 players, who are at a critical stage of their athletic development.

Despite the recognition of its importance, there is a noticeable gap in the literature regarding the development and implementation of comprehensive training modules that cater specifically to the tactical and technical needs of young field hockey players in Malaysia. Previous studies have often focused on either technical or tactical training in isolation, neglecting the benefits of an integrated approach. This research seeks to address this gap by developing and evaluating a tactical and technical training module designed for under-16 field hockey players in Malaysia. The problem statement of this study revolves around the current inadequacies in the training programs for young field hockey players in Malaysia. Specifically, the lack of a cohesive tactical and technical training module has resulted in suboptimal player performance at the national and international levels (McEwan & Crawford, 2022; Muthiaine, 2014). The research questions guiding this study are: (i) How does the implementation of a tactical and technical training module affect the performance of under-16 field hockey players in Malaysia? (ii) What are the specific technical and tactical improvements observed in players after participating in the module? This study aim to evaluate the effectiveness of a structured tactical and technical training module on the performance of under-16 field hockey players in Malaysia.

The significance of this study lies in its potential to revolutionize the training practices for young field hockey players in Malaysia. By providing empirical evidence on the effectiveness of an integrated tactical and technical training module, the study could inform future coaching strategies and contribute to the development of more competitive field hockey players at the national level. Furthermore, this research could serve as a benchmark for similar studies in other countries, thereby contributing to the global body of knowledge on field hockey training.

Materials and Method

Research Design

This study will utilize a quasi-experimental design with a pre-test and post-test control group structure. The research aims to compare the effectiveness of a newly developed tactical and technical training module on the performance of under-16 field hockey players in Malaysia. The study will involve two groups: an intervention group that will receive the specific training module and a control group that will follow their regular training routine. Both groups will be assessed on their knowledge and skills related to ball action/direction, opponents' action, positioning, and action during changing situations before and after the intervention.

Sampling

Participants for this study will be selected using purposive sampling, targeting under-16 field hockey players who are actively involved in the sport. A total of 40 participants from various schools and clubs across Malaysia will be recruited. These participants will be randomly assigned to either the intervention group (n = 20) or the control group (n = 20). Inclusion criteria include having at least one year of active participation in field hockey and being free from injuries that could impede performance during the study. Random assignment will ensure that any differences observed between the two groups can be attributed to the intervention rather than other variables.

Instrumentation

The primary instrument in this study will be the tactical and technical training module developed by the researcher. This module consists of carefully designed sessions aimed at improving players' understanding and execution of tactical and technical aspects of the game, focusing on ball action/direction, opponents' actions, positioning, and decision-making during changing situations. The module will be implemented over eight weeks, with three sessions per week, each lasting 90 minutes. The training sessions will progressively build on each other, starting with foundational skills and moving towards complex tactical scenarios that mimic real-game situations.

In addition to the training module, the study will use pre-established assessment tools to evaluate participants' knowledge and performance in the four key areas: ball action/direction, opponents' action, positioning, and actions during changing situations. These assessments will involve both theoretical tests to evaluate players' knowledge and practical drills to assess their application of this knowledge during gameplay.

Data Collection Procedures

Data will be collected at two time points: before the intervention (pre-test) and after the completion of the eight-week training program (post-test). During the pre-test phase, both the intervention and control groups will undergo assessments to establish baseline data in the four key areas. These assessments will include both written tests to measure theoretical knowledge and practical assessments to evaluate on-field performance. The intervention group will then participate in the eight-week tactical and technical training module, while the control group will continue with their usual training routines. During the intervention period, the researcher will monitor and record the adherence of the

intervention group to the module to ensure the fidelity of the intervention. At the end of the eight weeks, both groups will again be assessed using the same theoretical and practical assessments employed during the pre-test phase. This will allow for a direct comparison of pre-test and post-test scores within and between the two groups.

Statistical Analysis

The data collected from the pre-test and post-test assessments will be analyzed using Multivariate Analysis of Variance (MANOVA) to determine the impact of the tactical and technical training module on the participants' knowledge and performance across the four key areas:

1. Knowledge about ball action/direction.
2. Knowledge about opponents' action.
3. Positioning.
4. Action during changing situations.

MANOVA is appropriate for this study as it allows for the analysis of multiple dependent variables simultaneously, thereby accounting for the potential intercorrelations among them. This statistical method will be used to assess whether there are significant differences in the combined dependent variables between the intervention and control groups, as well as between pre-test and post-test scores. If the MANOVA reveals significant differences, follow-up univariate ANOVAs will be conducted for each dependent variable to pinpoint where these differences occur. The significance level for all tests will be set at $p < 0.05$. Additionally, effect sizes (partial eta squared) will be calculated to determine the magnitude of the differences observed. Data will be analyzed using statistical software such as SPSS to ensure the accuracy and reliability of the results. By employing this robust analytical approach, the study will be able to provide detailed insights into the effectiveness of the tactical and technical training module, with implications for improving coaching practices and player development strategies in field hockey, particularly in the Malaysian context.

Results

Demographic Characteristics of Participants

The demographic characteristics of the participants are summarized in Table 1. The table includes details such as age, years of playing experience, and the number of training hours per week. Both the intervention and control groups were well-matched on these demographic variables, ensuring that any differences observed in the study could be attributed to the intervention rather than to demographic differences.

Table 1. Demographic Characteristics of Participants (n = 40)

Variable	Intervention Group (n = 20)	Control Group (n = 20)	Total (n = 40)
Mean Age (years)	15.4 ± 0.6	15.3 ± 0.7	15.35 ± 0.65
Years of Experience	3.8 ± 1.2	3.7 ± 1.3	3.75 ± 1.25
Training Hours per Week	6.5 ± 1.0	6.4 ± 1.1	6.45 ± 1.05

Note: Values are presented as mean ± standard deviation.

Explanation: Table 1 shows that the participants in both the intervention and control groups were similar in terms of age, years of playing experience, and the number of training hours per week. This demographic matching helps to control for potential confounding variables, allowing for a more accurate assessment of the intervention's effects.

Descriptive Statistics of Study Variables

The mean and standard deviation for each of the key variables (knowledge about ball action/direction, knowledge about opponents' action, positioning, and action during changing situations) at both pre-test and post-test stages are presented in Table 2. These statistics provide an overview of the central tendency and dispersion of scores within each group.

Table 2. Mean and Standard Deviation of Study Variables (n = 40)

Variable	Time Point	Intervention Group (n = 20)	Control Group (n = 20)
Knowledge about Ball Action/Direction	Pre-test	65.2 ± 5.3	64.8 ± 5.5
	Post-test	78.5 ± 4.7	66.1 ± 5.4
Knowledge about Opponents' Action	Pre-test	62.7 ± 5.9	63.1 ± 5.7
	Post-test	76.3 ± 5.2	64.2 ± 5.8
Positioning	Pre-test	60.4 ± 6.1	60.9 ± 6.0
	Post-test	74.6 ± 5.9	61.2 ± 6.1
Action during Changing Situations	Pre-test	59.8 ± 6.5	59.5 ± 6.7
	Post-test	73.9 ± 5.8	60.1 ± 6.4

Note: Values are presented as mean ± standard deviation.

Explanation: Table 2 highlights the descriptive statistics of the study variables. In the pre-test phase, the intervention and control groups had similar scores across all four variables. However, in the post-test phase, the intervention group showed substantial improvements in all areas, while the control group's scores remained relatively stable.

Inferential Statistics: MANOVA Results

The MANOVA was conducted to determine whether there were significant differences between the intervention and control groups across the four dependent variables (knowledge about ball action/direction, knowledge about opponents' action, positioning, and action during changing situations). The results of the MANOVA, including the multivariate tests and follow-up univariate ANOVAs, are presented in Table 3.

Explanation: Table 3 shows that there were significant multivariate effects of the group (Wilks' Lambda = 0.327, $F = 9.867$, $p = 0.001$, Partial Eta Squared = 0.673), indicating that the intervention had a significant impact on the combined dependent variables. Follow-up univariate ANOVAs revealed that the intervention group showed significantly greater improvements in all four variables (knowledge about ball action/direction, knowledge about opponents' action, positioning, and action during changing situations) compared to the control group. The effect sizes (Partial Eta Squared) for each variable suggest a substantial impact of the intervention. These results demonstrate that the tactical

Table 3. MANOVA Results for the Effect of the Tactical and Technical Training Module (n = 40)

Effect	Wilks' Lambda	F	p-value	Partial Eta Squared
Group (Intervention vs. Control)	0.327	9.867	0.001	0.673
Variable				
- Knowledge about Ball Action/Direction		16.754	0.001	0.307
- Knowledge about Opponents' Action		15.982	0.001	0.295
- Positioning		14.642	0.002	0.276
- Action during Changing Situations		13.689	0.003	0.262

and technical training module was effective in enhancing the critical skills and knowledge areas of under-16 field hockey players in Malaysia, highlighting the module's potential for broader application in similar training contexts.

Discussion

The findings of this study provide important insights into the effectiveness of a tactical and technical training module on the performance of under-16 field hockey players in Malaysia. The significant improvements observed in the intervention group across all four variables—knowledge about ball action/direction, knowledge about opponents' action, positioning, and action during changing situations—underscore the potential of structured training programs in enhancing young athletes' tactical and technical competencies. The first variable, knowledge about ball action/direction, showed a significant increase in the intervention group compared to the control group. This improvement aligns with previous studies, which have demonstrated that focused tactical training can enhance players' understanding and anticipation of ball movement, leading to better decision-making during games (Osman et al., 2020). The ability to predict and react to ball direction is crucial in field hockey, as it enables players to position themselves advantageously, thus increasing their effectiveness on the field.

The second variable, knowledge about opponents' action, also showed substantial gains in the intervention group. Understanding opponents' actions is a critical aspect of tactical intelligence in team sports, and this study's results are in line with those of (Roca, Ford & Memmert, 2018) who reported that players trained in tactical scenarios were better at predicting and countering opponents' strategies. This heightened awareness allows players to anticipate and disrupt opponents' plays, contributing to more effective defensive and offensive maneuvers. The improvement in this variable suggests that the module effectively enhanced the players' ability to read and respond to opponents' movements, a key skill in competitive play. Positioning, the third variable, showed marked improvement in the intervention group as well. Positioning is a fundamental tactical skill that determines a player's ability to contribute effectively to both defense and attack. The findings of this study are supported by (Williams & Hodges, 2005), who emphasized the importance of positional play in sports and noted that athletes who received structured tactical training exhibited superior positioning and spatial awareness. The ability to be in the right place at the right time can often be the difference between success and failure in field hockey, making this a critical area of development for young players.

Finally, action during changing situations—a variable that assesses players' adaptability and decision-making under dynamic conditions—showed significant improvements in the intervention group. This result aligns with the work of (Raab, 2012), who found that athletes trained under variable and unpredictable conditions develop better decision-making skills and are more adaptable during gameplay. The significant gains in this area highlight the effectiveness of the training module in preparing players for the fluid and fast-paced nature of field hockey, where situations can change rapidly, requiring quick and accurate decisions. The results of this study contribute to the growing body of literature on the importance of tactical and technical training in youth sports. While previous research has highlighted the benefits of such training programs, this study specifically adds to the understanding of their impact in the context of Malaysian field hockey. The findings suggest that structured training modules, like the one developed in this study, can significantly enhance young athletes' performance by improving their tactical knowledge and technical execution.

Conclusion

This study demonstrated that the tactical and technical training module significantly improved the performance of under-16 field hockey players in Malaysia across four key areas: knowledge about ball action/direction, knowledge about opponents' action, positioning, and action during changing situations. The intervention group's significant improvements compared to the control group underscore the effectiveness of the module in enhancing tactical and technical skills critical for competitive play. These findings align with previous research, affirming the value of structured, scenario-based training programs in youth sports development.

Recommendations

Based on the findings, it is recommended that field hockey coaches and sports educators incorporate structured tactical and technical modules into their training routines, particularly for young players. The module developed in this study can serve as a template for such programs, with potential adaptations for different age groups and skill levels. Future research should explore the long-term effects of these training programs on player development and investigate their applicability in other sports and cultural contexts. Additionally, integrating psychological skills training alongside tactical and technical training could further enhance players' overall performance.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Розгляд впливу застосування модуля з тактико-технічної підготовки на показники результативності гравців з хокею на траві у віковій категорії U-16 у Малайзії: Квазі-експериментальний метод

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Реферат. Стаття: 6 с., 3 табл., 15 джерел.

Історія питання. Розвиток тактичних і технічних навичок має вирішальне значення для юних спортсменів, які займаються командними видами спорту, зокрема хокеєм на траві, де швидкість прийняття рішень і стратегічна гра є ключовими аспектами для досягнення успішних результатів.

Мета дослідження. Мета цього дослідження полягала в оцінці ефективності застосування структурованого модуля з тактико-технічної підготовки на показники результативності гравців з хокею на траві у віковій категорії U-16 у Малайзії.

Матеріали та методи. У процесі дослідження було використано квазі-експериментальний метод, що передбачав залучення 40 учасників, які були розподілені за принципом рандомізації до інтервенційної групи (n = 20) або контрольної групи (n = 20). Учасники інтервенційної групи проходили восьмитижневий модуль з тактико-технічної підготовки, в той час як контрольна група продовжувала тренування за стандартною програмою. Проведено перед- та післятестовий аналіз з метою визначення якості знань та показників результативності у чотирьох ключових сферах: дії з м'ячем/спрямування м'яча, дії суперників, позиціонування та виконання комплексу дій в умовах зміни ігрових ситуацій. За допомогою багатовимірного дисперсійного аналізу (Multivariate Analysis of Variance, MANOVA) проаналізовано дані щодо оцінки впливу інтервенції.

Результати. За результатами багатовимірного дисперсійного аналізу MANOVA встановлено значне покращення показників в інтервенційній групі за всіма чотирма змінними порівняно з контрольною групою (Лямбда Вілкса = 0,327, F = 9,867, p = 0,001). Зокрема, учасники інтервенційної групи продемонстрували суттєві здобутки в розумінні аспектів щодо виконання дій з м'ячем/спрямування м'яча, дій суперників, позиціонування та реалізації комплексу дій в умовах зміни ігрових ситуацій. Отримані результати підкреслюють ефективність тренувального модуля в контексті покращення тактико-технічних компетенцій у юних гравців з хокею на траві. Дослідження демонструє, що структурований тактико-технічний тренувальний модуль сприяє значному поліпшенню показників результативності гравців з хокею на траві віком до 16 років.

Висновки. Результати дослідження вказують на потенціал ширшого застосування зазначених модулів у програмах розвитку юнацького спорту. Тренерам рекомендується інтегрувати подібні тренувальні структури задля оптимізації розвитку гравців та результативності змагальної діяльності.

Ключові слова: хокей на траві, тактична підготовка, технічні навички, юнацький спорт, підвищення результативності, Малайзія.

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Identifying Variations in Motor Fitness Components among Upper Primary and Secondary School Male Students

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Abstract

Background. Motor fitness helps students develop academically and socially. The students are more engaged in fitness activities with classmates of similar skills. Therefore, motor fitness programs should address kids' capacity to increase physical activity.

Objectives. The study aimed to ascertain variations in upper primary and secondary school male students with respect to selected motor fitness components, i.e. strength (standing broad jump), speed (50-meter sprint) and endurance (800-meter run).

Materials and methods. A total of 150 male students, aged 12 to 16, from five schools in Delhi, India, participated in this study. The students were divided into five groups, each consisting of 30 students from both private and government schools. The study assessed three motor fitness components: strength (measured by the standing broad jump), speed (measured by a 50-meter sprint), and cardiovascular endurance (measured by an 800-meter run). The one-way ANOVA was used to identify significant differences among the groups, with post hoc LSD tests performed for pairwise comparisons. A significance level of $p < 0.05$ was applied to all analyses.

Results. The analysis revealed statistically significant differences among the groups in all three motor fitness components: speed ($F(4,145) = 27.07$, $p < 0.05$), strength ($F_{(4,145)} = 16.93$, $p < 0.05$), and cardiovascular endurance ($F_{(4,145)} = 75.46$, $p < 0.05$). Post hoc analysis using the LSD test further indicated that students in each group differed significantly in strength, speed, and cardiovascular endurance when compared to one another.

Conclusions. The study concludes that male students in grades nine and ten demonstrate significantly higher levels of strength, speed, and cardiovascular endurance compared to students in grades six, seven, and eight. Therefore, motor fitness programs targeting these components should be tailored differently for upper primary and secondary school students to address their distinct developmental needs.

Keywords: upper primary and secondary school male students, strength, speed, endurance.

Introduction

Fitness is important for general health, especially in children. This study examines motor fitness differences among upper elementary and secondary school boys. Strength, speed, and endurance are examined in motor fitness. We compare motor fitness levels of upper elementary and secondary school boys by assessing these components. Understanding any differences between these age groups can help explain male pupils' physical development and activity patterns in school. This study will also examine if upper primary and secondary school boys' motor fitness components differ (Institute of Medicine, 2013).

Numerous health benefits, including improved cardiorespiratory fitness, muscle and bone health, and positive effects on mental and cognitive function, academic performance, and psychosocial health, have been linked to increased physical activity levels and intensities, according to previous research (Chaput et al., 2020). Psychosocial outcomes including self-concept, social behaviors, goal orientation, and, most importantly, self-efficacy can be enhanced by physically active training that is especially tailored to this purpose. These characteristics play a significant role in determining whether people engage in physical exercise now and in the future. In other words, increased

physical activity may also lead to improved psychosocial outcomes which in turn becomes a predictor for future participation in physical activity. Participation in physical activity in formative years becomes a predictor for engaging in health-enhancing behaviours in adulthood (Institute of Medicine, 2013). To maximize the benefits of students' involvement in physical activity and sports programs given by the school, it is vital to split them into groups of similar ability. This would enable children to participate in physical education and sports activities with classmates who possess similar abilities, fostering a high level of enthusiasm and engagement in the program (Hollett et al., 2022). This is evident in classroom research which suggests social status can impact the participation of students working in groups, potentially effecting interactions, learning outcomes, and social development (Hollett et al., 2022). Cohen's (1994) theory states that socially active kids learn better (Gillies, 2004). Kurt Lewin said that groups are dynamic and powerful organisms that can influence individuals and communities. The more cohesive a group, the more it can impact individuals. Similar views of group members suggest good group cohesiveness (Gençer, 2019).

Reza et al. (2024) highlight that motor fitness is vital for athletic success, as it integrates with techniques and tactics to enhance performance. It plays a key role in improving physical, mental, and psychosocial health, encompassing agility, balance, coordination, strength, reaction time, and speed crucial for assessing athletic capability (Mola & Bayisa, 2020).

All sports and motor skills require balance, coordination, agility, power, speed, and reaction time, which are interconnected with cardio, strength, endurance, flexibility, and body composition. Motor fitness, encompassing strength, endurance, speed, flexibility, and coordination, is crucial for efficient movement and physical fitness, demonstrated in activities like running, jumping, and weightlifting (Karmakar & Pradhan, 2018). Health-related physical fitness (HRPF), measured by body weight, cardiorespiratory fitness, musculoskeletal fitness, and flexibility, is linked to youth health outcomes (Cattuzzo et al., 2016). Motor skills develop with biological age, fitness, and body composition, with age and appropriate weight gain enhancing motor and cognitive functions (Bandyopadhyay & Basu, 2022). Recognizing the importance of motor fitness, Singh (2020) emphasizes that it should be developed during school years, noting variations in motor ability among boys from different geographic locations in Ghaziabad.

The motor fitness components of speed, strength, and endurance are the focus of this study. Speed, defined as the ability to cover distance quickly, is assessed using a 50 m sprint. Endurance refers to the capacity to sustain high-intensity activity over time, with an emphasis on heart rate control during endurance sports (Haugen et al., 2019) Strength, measured through the standing broad jump, indicates muscular force, while endurance is evaluated using an 800m run (Nadir & Nadir, 2022). Understanding variations in these components enables the development of tailored fitness programs, as exercises like calisthenics can significantly enhance speed, agility, and strength (Fenta & Mola, 2023). This study aims to establish whether there are any notably differences between the different age groups in terms of the baseline motor fitness components.

Materials and Methods

Participants

The research design of this study is descriptive, utilizing a survey conducted in Delhi City, India, across five public and government schools. The total population considered was 5,000 students. Out of this, 150 male students were selected using purposive and simple random sampling techniques. Each group consisted of thirty (n = 30) male students aged 12-16, representing five different grade levels: sixth, seventh, and eighth (Upper Primary) and ninth and tenth (Secondary).

Variables and Criterion Measures

The investigation concentrated on three critical fitness indicators: endurance, speed, and strength. The appropriate testing techniques and apparatus were employed to measure these parameters.

Test Procedure

Speed was assessed by administering a 50-meter sprint, in which participants were instructed to run as rapidly as possible in a straight line. The test was conducted twice, with the fastest time being recorded to the nearest 0.1 seconds (Shang et al., 2010). The Standing Broad Jump (SBJ) is a dependable test that is employed to evaluate the strength and power of the lower limbs. Participants are required to stand with their heels on a line and then leap horizontally as far as they can without receiving specific instructions regarding leg or arm movements. The distance of the leap is determined by measuring the distance from the start line to the heel closest to the start after both feet have landed together (Thomas et al., 2020). Endurance (800 mt) the subject's fundamental endurance is assessed through this examination, which is contingent upon their maximum aerobic capacity. The test was conducted on a 400-meter track in groups of 8 to 10 individuals at a time. Upon receiving the start signal, the participants were obligated to complete two circuits of running. The subjects were instructed to maintain a consistent pace throughout the run, remaining near the inner border of the track. In the event that a subject was fatigued, they were permitted to slow down or even walk for a short distance in order to recover and subsequently recommence running (Megahed et al., 2023).

Selection of Variables

The subsequent variables were chosen for the study in consideration of the scholar's personal knowledge of the field of study, administrative feasibility, and the availability of instruments/equipment.

The subjects were put to the test using the correct testing techniques for each of the motor fitness components that were

Table 1. List of variables, tests to be used and their units of measurement

No	Variable	Test Used	Unit of Measurement
1	Strength	Standing Broad Jump	Centimeter
2	Speed	50 m Run	Second
3	Endurance	800 m Run	Minute

chosen. The student received the assistance of other teachers to gather data, and before the test, all of the helpers received training on how to administer tests properly. In order to prevent tiredness from setting in, the test time was altered. Between tests, there was enough time for the subjects to exert themselves to the fullest. All tests were administered to the subjects while they were dressed in their appropriate athletic attire.

Analysis of Data

Descriptive statistics were implemented to evaluate the data that was acquired. The designated physical fitness of the participants is analysed using descriptive statistics, which entails the transformation of mean, standard deviation, frequency distribution, and graphics into meaningful concepts using SPSS Version 26 software. One-way analysis of variance was used. In case F-value is significant, post-hoc test (LSD) was used. The level of significance chosen was 0.05.

Results

Table 2 reveals the descriptive analysis of Speed (50 m Sprint) in respect of male subjects studying in classes' six to ten. The mean value of 5 m sprint for male subjects studying in class six is 9.17 class seven is 9.11 class eight is 9.13 class nine is 8.41 and class ten is 8.29. The standard deviation value in respect of subjects studying in class six is 0.65 class seven is class 0.35 eight is 0.42 class nine is 0.28 and class ten is 0.48.

The means and standard deviations in respect of Speed (50 m sprint) in the case of male students studying in classes to six and ten are graphically presented in Fig. 1.

From table 3 it is clearly seen that the F-value of 27.07 is statistically significant at 0.05 level of confidence with 4 and 145 degrees of freedom.

Table 3. Analysis of Variance for Speed (50 m Sprint) in respect of Male Subjects Studying in Classes Six to Ten

Dependent Variable		Sum of Squares	df	Mean Square	F
Speed (50 m Sprint)	Between Groups	22.43	4	5.61	27.07*
	Within Groups	30.04	145	0.21	
	Total	52.47	149		

*Significant at 0.05 level. $F_{0.05\ (4\ \&\ 145)} = 2.43$

In order to ascertain the superiority of different classes i.e. classes six to ten with respect to Speed (50 m Sprint), post-hoc test i.e. Least Significant Difference (LSD) Method was used and analysis of data pertaining to this is presented in the following table 4.

The table above plainly demonstrates that there is no significant difference between male students in classes six, seven, and eight with respect to Speed (50 m Sprint). Similarly, there is no significant difference in the same variable between male pupils in classes nine and ten. However, the performance of male students studying in classes nine and ten is significantly superior to that of male students studying in classes six, seven and eight.

Table 5 reveals the descriptive analysis of Strength (Standing Broad Jump) in respect of male subjects studying in classes' six to ten. The mean value of strength for male subjects studying in class six is 120.20 class seven is 120.50 class eight is 120.33 class nine is 145.17 and class ten is 145.33. The standard deviation value in respect of subjects studying in class six is 9.24 class seven is 20.85 class eight is 11.74 class nine is 20.91 and class ten is 23.52.

The means and standard deviations in respect of Strength (Standing Broad Jump) in the case of male students studying in classes to six and ten are graphically presented in Fig. 2.

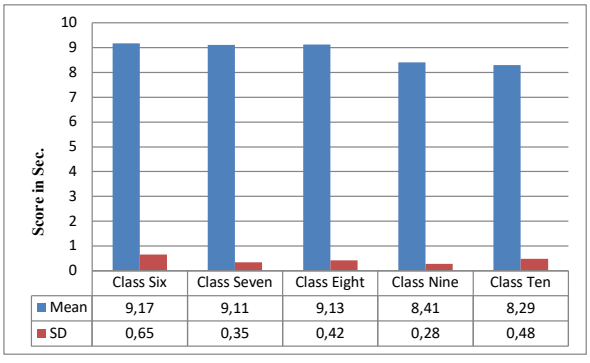

Fig. 1 Means and Standard Deviations in respect of Speed (50 m sprint) in the case of male students studying in classes to six and ten

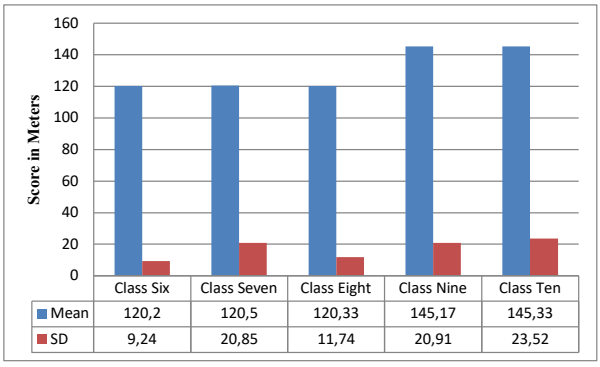

Fig. 2. Means and Standard Deviations in respect of Strength (Standing Broad Jump) in the case of male students studying in classes to six and ten

Table 2. Descriptive Statistics for Speed (50 m Sprint) in Respect of Male Students Studying in Upper Primary Classes i.e. six to eight and Secondary Classes i.e. nine and ten

Dependent Variable		n	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean	
						Lower Bound	Upper Bound
Speed (50 m sprint)	Class Six	30	9.17	0.65	0.12	8.92	9.41
	Class Seven	30	9.11	0.35	0.06	8.97	9.24
	Class Eight	30	9.13	0.42	0.08	8.97	9.29
	Class Nine	30	8.41	0.28	0.05	8.30	8.51
	Class Ten	30	8.29	0.48	0.09	8.11	8.47

Table 4. Post Hoc Test (Multiple Comparisons using LSD) for Speed (50 m Sprint) in the case of Male Subjects Studying in Classes Six to Ten

Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	95 % Confidence Interval	
				Lower Bound	Upper Bound
Speed (50 m Sprint)	Class Six	Class Seven	0.06	-0.17	0.29
		Class Eight	0.03	-0.19	0.27
		Class Nine	0.76*	0.53	0.99
		Class Ten	0.87*	0.64	1.11
	Class Seven	Class Six	-0.06	-0.29	0.17
		Class Eight	-0.03	-0.26	0.21
		Class Nine	0.70*	0.47	0.93
		Class Ten	0.81*	0.58	1.05
	Class Eight	Class Six	-0.03	-0.27	-0.20
		Class Seven	-0.03	-0.21	0.26
		Class Nine	0.72*	0.49	0.96
		Class Ten	0.84*	0.61	1.72
	Class Nine	Class Six	-0.76*	-0.99	-0.53
		Class Seven	-0.70*	-0.93	-0.47
		Class Eight	-0.72*	-0.96	-0.49
		Class Ten	0.12	-0.12	0.35
	Class Ten	Class Six	-0.87*	-1.11	-0.64
		Class Seven	-0.81*	-1.05	-0.58
		Class Eight	-0.84*	-1.07	-0.61
		Class Nine	-0.12	-0.35	0.12

*Significant at 0.05 level

Table 5. Descriptive Statistics for Strength (Standing Broad Jump) in Respect of Male Students Studying in Upper Primary Classes i.e. six to eight and Secondary Classes i.e. nine and ten

Dependent Variable		n	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean	
						Lower Bound	Upper Bound
Strength (Standing Broad Jump)	Class Six	30	120.20	9.24	1.69	116.75	123.65
	Class Seven	30	120.50	20.85	3.81	122.71	128.29
	Class Eight	30	120.33	11.74	2.14	115.95	124.72
	Class Nine	30	145.17	20.91	3.82	137.36	152.97
	Class Ten	30	145.33	23.52	4.29	136.55	154.12

Table 6. Analysis of Variance for Strength (Standing Broad Jump) in respect of Male Subjects Studying in Classes Six to Ten

Dependent Variable		Sum of Squares	df	Mean Square	F
Strength (Standing Broad Jump)	Between Groups	22332.09	4	5583.02	16.93*
	Within Groups	47809.80	145	329.72	
	Total	70141.89	149		

*Significant at 0.05 level. $F_{0.05\,(4\,\&\,145)} = 2.43$

It is evident from table 5 that the F-value of 16.93 is statistically significant at the 0.05 level of confidence, with 4 and 145 degrees of freedom. The following table presents the analysis of data pertinent to the post-hoc test, which was conducted using the Least Significant Difference (LSD) Method, to determine the superiority of various classes, specifically classes six to ten, in terms of Strength (Standing Broad Jump).

Table 7 clearly shows that with respect to Strength (Standing Broad Jump) the difference among classes six, seven and eight as well as between classes nine and ten is statistically not significant whereas performance in the same variable of male subjects studying in classes nine and ten is statistically superior to that of male students studying in classes six, seven and eight at 0.05 level of confidence.

Table 8 reveals the descriptive analysis of Endurance (800 m Run) in respect of male subjects studying in classes' six to ten. The mean value of endurance for male subjects studying in class six is 4.89 class seven is 4.87 class eight is 4.86 class nine is 3.84 and class ten is 3.85. The standard deviation value in respect of subjects studying in class six is 0.40 class seven is class 0.37 eight is 0.39 class nine is 0.30 and class ten is 0.31.

Table 7. Post Hoc Test (Multiple Comparisons using LSD) in the case of Strength (Standing Broad Jump) with respect to class six, class seven, class eight, class nine and class ten

Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	95 % Confidence Interval	
				Lower Bound	Upper Bound
Strength (Standing Broad Jump)	Class Six	Class Seven	-0.30	-0.42	0.42
		Class Eight	-0.13	-9.57	8.97
		Class Nine	-24.97*	-9.40	9.13
		Class Ten	-25.13*	-34.23	-15.70
	Class Seven	Class Six	0.300	-34.40	-15.87
		Class Eight	0.167	-8.97	9.57
		Class Nine	-24.67*	-9.10	9.43
		Class Ten	-24.83*	-33.93	-15.40
	Class Eight	Class Six	0.13	-34.10	-15.57
		Class Seven	-0.17	-9.13	9.40
		Class Nine	-24.83*	-9.43	9.10
		Class Ten	-25.00*	-34.10	-15.57
	Class Nine	Class Six	24.97*	-34.27	-15.73
		Class Seven	24.67*	15.70	34.23
		Class Eight	24.83*	15.40	33.93
		Class Ten	-0.17	15.57	34.10
	Class Ten	Class Six	25.13*	-9.43	9.10
		Class Seven	24.83*	15.40	33.93
		Class Eight	25.00*	15.57	34.10
		Class Nine	0.167	-9.43	9.10

*Significant at 0.05 level

Table 8. Descriptive Statistics for Endurance (800m Run) in Respect of Male Students Studying in Upper Primary Classes i.e. six to eight and Secondary Classes i.e. nine and ten

Dependent Variable		n	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean	
						Lower Bound	Upper Bound
Endurance	Class Six	30	4.89	0.40	0.07	4.74	5.03
	Class Seven	30	4.87	0.37	0.07	4.73	5.00
	Class Eight	30	4.86	0.39	0.07	4.72	5.00
	Class Nine	30	3.84	0.30	0.05	3.73	3.95
	Class Ten	30	3.85	0.31	0.06	3.74	3.97

The means and standard deviations in respect of Endurance (800 m Run) in the case of male students studying in classes to six and ten are graphically presented in Fig. 3.

The analysis of data in the above table clearly shows that the F value of 75.46 is statistically significant at 0.05 level of confidence with 4 and 145 degrees of freedom. In order to ascertain the superiority of different classes i.e. classes six to ten with respect to Endurance (800 m Run), post-hoc test i.e. Least Significant Difference (LSD) Method was used and analysis of data pertaining to this is presented in the following table.

Table 10 clearly shows that with respect to Endurance (800m Run) the difference among classes six, seven and eight as well as between classes nine and ten is statistically not significant whereas performance in the same variable of male subjects studying in classes nine and ten is statistically superior to that of male students studying in classes six, seven and eight at 0.05 level of confidence.

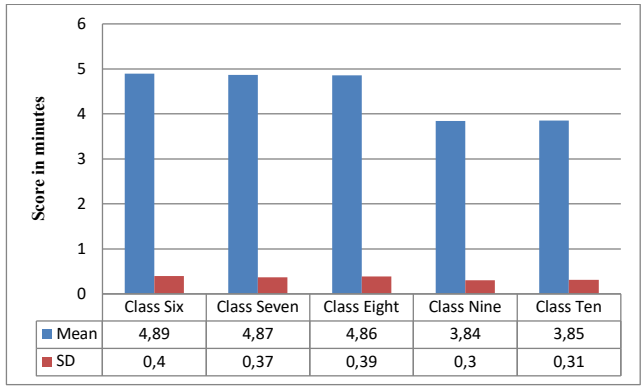

Fig 3. Means and Standard Deviations in respect of Endurance (800 m Run) in the case of male students studying in classes to six and ten

Table 9. Analysis of Variance for Endurance (800 m Run) in respect of Male Subjects Studying in Classes Six to Ten

Dependent Variable		Sum of Squares	df	Mean Square	F
Endurance (800 m Run)	Between Groups	37.83	4	9.46	75.46*
	Within Groups	18.18	145	0.13	
	Total	56.01	149		

*Significant at 0.05 level. $F_{0.05\ (4\ \&\ 145)} = 2.43$

Table 10. Post Hoc Test (Multiple Comparisons using LSD) in the case of Endurance (800 m Run) with respect to males studying in classes six to ten

Dependent Variable	(I) Group	(J) Group	Mean Difference (I-J)	95% Confidence Interval	
				Lower Bound	Upper Bound
Endurance	Class Six	Class Seven	0.02	-.1643	.1970
		Class Eight	0.03	-.1553	.2060
		Class Nine	1.05*	.8657	1.2270
		Class Ten	1.03*	.8507	1.2120
	Class Seven	Class Six	-0.02	-.1970	.1643
		Class Eight	0.01	-.1717	.1897
		Class Nine	1.03*	.8493	1.2107
		Class Ten	1.02*	.8343	1.1957
	Class Eight	Class Six	-0.03	-.2060	.1553
		Class Seven	-0.01	-.1897	.1717
		Class Nine	1.02*	.8403	1.2017
		Class Ten	1.01*	.8253	1.1867
	Class Nine	Class Six	-1.05*	-1.2270	-.8657
		Class Seven	-1.03*	-1.2107	-.8493
		Class Eight	-1.02*	-1.2017	-.8403
		Class Ten	-0.02	-.1957	.1657
	Class Ten	Class Six	-1.03*	-1.2120	-.8507
		Class Seven	-1.02*	-1.1957	-.8343
		Class Eight	-1.01*	-1.1867	-.8253
		Class Nine	0.02	-.1657	.1957

Significant at 0.05 level

Discussion

In the present study motor fitness components of students of upper primary and secondary students (class 6-10) in Delhi have been evaluated and compared with each other. Motor fitness refers to a person's physical activity abilities (Vanhees et al., 2005). Skill-related fitness and health-related fitness measure a person's physical ability to do physical activity tasks. Motor fitness includes physical fitness and basic movement efficiency (Gula 2024). From nine to eighteen, adolescence occurs. This stage of human development is crucial for optimum health. Teens grow rapidly physically, cognitively, and psychosocially. Most of the subjects were early adolescents (10-13 years) while a few were middle adolescents (14-17 years). Neurological development and movement control progress cephalocaudally and proximo-distally. Due to these changes in body dimensions, motor skills develop predictably. Also, neurological development impacts skill progression. Physically active and idle kids go through the same stages. Physical activity for young children is necessary for skill development, not stage progression (Mola &Shaw, 2024; Backes & Bonnie 2019).

According to research, age and sex-related variations in health- and performance-related fitness are significantly linked to tissue and system development during childhood and adolescence. Genetic factors limit capacity, but environmental and behavioural influences, particularly physical activity, affect how much capacity an individual achieves (Brown et al., 2017). Growth is modest during puberty (10-12 years), but a strength spurt occurs in teenagers and continues after boys are biologically adults. Later in puberty, height and weight develop most, improving motor performance. Growing children have far greater cardiorespiratory endurance. Adolescent males progress till 17-18 (Mintjens, S. et al, 2018). This explains why upper primary and secondary pupils may have different endurance levels. Strength growth curves mirror body weight and skeletal muscle mass growth curves because muscle strength is related to muscle cross-sectional area. Child strength rises linearly, so as they approach adolescence, so does strength. Speed is a performance-related fitness factor that changes predictably with tissue and system development. Running speed and muscle power depend on neuromuscular system development (Institute of Medicine. 2013). According to research, bodily strength, speed, and endurance increase

predictably during development. It also implies that training can considerably improve these qualities. The current study shows that sports and physical fitness programs should be age-specific and take into account children's physiological changes and ability levels (Hughes et al, 2018). Research reveals that environment and socio-cultural factors affect motor competence, or the ability to perform motor skill-related tasks. Motor skills predict future physical activity. If a kid thinks they can play a sport or run, they're more likely to do so than if they think they can't (Derikx et al, 2021).

Conclusions

Based on the findings of the present study, it can be concluded that there is a significant performance gap between male pupils in grades 9 and 10 compared to those in grades 6, 7, and 8. The analysis across key physical parameters speed (50-meter sprint), strength (standing broad jump), and endurance (800-meter run) revealed that while there are no substantial differences between upper primary (grades 6, 7, and 8) and secondary (grades 9 and 10) pupils in these categories, the overall performance of male students in grades 9 and 10 is notably superior. This suggests that age, physical development, and possibly training practices contribute to the observed differences in physical abilities between these grade levels.

Acknowledgment

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Conflicts of Interest

The authors declare no conflicts of interest.

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Визначення відмінностей у компонентах рухової підготовленості серед учнів чоловічої статі старшої та середньої школи

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

Реферат. Стаття: 8 с., 10 табл., 3 рис., 25 джерел.

Історія питання. Рухова підготовленість сприяє академічному та соціальному розвитку школярів. Учні більш залучені до занять фізичною підготовкою з однокласниками, які володіють схожими навичками. Таким чином, програми з рухової підготовленості мають враховувати здатність дітей до збільшення рівня фізичної активності.

Мета дослідження. Дослідження мало на меті з'ясувати відмінності в учнів чоловічої статі старшої та середньої школи щодо окремих компонентів рухової підготовленості, а саме показників сили (стрибок у довжину з місця), швидкості (спринтерський біг на 50 метрів) та витривалості (біг на 800 метрів).

Матеріали та методи. У дослідженні взяли участь 150 учнів чоловічої статі віком від 12 до 16 років з п'яти шкіл міста Делі, Індія. Учні були розділені на п'ять груп, кожна з яких складалася з 30 учнів як з приватних, так і з державних шкіл. У дослідженні оцінювалися три компоненти рухової підготовленості: сила (вимірюється шляхом виконання стрибка у довжину з місця), швидкість (вимірюється за допомогою спринтерського бігу на 50 метрів) і витривалість серцево-судинної системи (вимірюється за допомогою бігу на 800 метрів). З метою встановлення значущих відмінностей між групами використовувався односторонній дисперсійний аналіз (ANOVA), а для попарних порівнянь проводився post hoc тест на визначення найменшої істотної різниці (LSD — Least significant difference test). Рівень значущості $p < 0,05$ застосовувався до всіх аналізів.

Результати. За результатами аналізу встановлено статистично значущі відмінності між групами в усіх трьох компонентах рухової підготовленості: швидкості ($F_{(4,145)} = 27,07$, $p < 0,05$), силі ($F_{(4,145)} = 16,93$, $p < 0,05$) та витривалості серцево-судинної системи ($F_{(4,145)} = 75,46$, $p < 0,05$). Post hoc аналіз з використанням тесту на визначення найменшої істотної різниці також вказав на суттєву різницю в показниках сили, швидкості та витривалості серцево-судинної системи в кожній групі порівняно з іншими групами.

Висновки. На основі проведеного дослідження можна зробити висновок, що учні дев'ятих і десятих класів чоловічої статі демонструють значно вищі показники сили, швидкості та витривалості серцево-судинної системи порівняно з учнями шостих, сьомих і восьмих класів. Отже, програми рухової підготовленості, спрямовані на розвиток зазначених компонентів, мають бути розроблені за диференційованим підходом для учнів старшої та середньої школи відповідно до їхніх особливих потреб розвитку.

Ключові слова: учні чоловічої статі старшої та середньої школи, сила, швидкість, витривалість.

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Original Scientific Article

Assessing Strength Effort in Pre-Adolescent Girls: Insights into Effort Accuracy at Different Strength Thresholds

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Abstract

Objectives. This study aimed to examine the peculiarities of strength effort assessment in girls aged 10, 11, and 12 years. Specifically, it sought to understand how these age groups evaluate effort at different percentages of their maximum strength (1/3, 1/2, and 2/3).

Materials and methods. The study involved 75 girls divided into three age groups: 10 years (n = 20), 11 years (n = 25), and 12 years (n = 30). Participants' maximum hand strength was measured using a dynamometer, and their ability to assess effort at 1/3, 1/2, and 2/3 of this maximum was recorded.

Results. The error of effort assessment was calculated and analyzed using paired and independent samples t-tests. Statistical significance was set at $\alpha = 0.05$. The analysis revealed no significant age-related differences in hand maximum strength or strength effort assessment among the different age groups. The most accurate assessment of effort occurred at 2/3 of maximum strength for all age groups. Significant differences were found in effort assessment between 1/3 and 1/2 of maximum strength, and between 1/3 and 2/3 of maximum strength, with improvements noted as the effort percentage increased. However, no significant differences were observed between effort levels at 1/2 and 2/3 of maximum strength.

Conclusions. The study indicates that the ability to assess strength effort remains stable across the age range of 10 to 12 years, with the most precise assessment occurring at 2/3 of maximum strength. The findings suggest that while overall strength assessment abilities are consistent, targeted training may enhance precision at different effort levels. This contributes to the understanding of motor function development and highlights the need for interventions to improve effort assessment skills in young girls.

Keywords: strength effort assessment, motor development, young girls, maximum strength, kinesthetic sensitivity.

Introduction

Participating in sports and physical activity not only shapes our bodies but also serves as a transformative experience that nurtures both our physical and mental well-being (Choudhary & Dubey, 2024). Physical education plays a crucial role in the development of motor abilities in children and adolescents. Physical activity is essential daily (Mario & Das, 2022). The involvement of young individuals in various motor activities can lead to the integration of their way of thinking and behaving into their personality (Bălan et al., 2012). Quality physical education has been widely

recognized as paramount for children and youth to attain motor competence and become physically active throughout their lifespan (Santos et al., 2019). Movement experiences are recognized as educationally desirable in the early life of the child, and this is the time when a solid movement foundation can be developed, providing children with a base for future physical development and achievement in various forms of physical activity (Ikechukwu et al., 2019). While traditional approaches have often focused on discrete motor skills, there is a growing recognition that motor abilities are influenced by a range of interrelated factors, including cognitive, social, and environmental considerations (Harris et al., 2015). The relationship between motor skills and academic performance has been a particular area of interest, with studies suggesting that fine motor skills and executive function both contribute to academic achievement in the early years of schooling (Cameron et al., 2012). Movement coordination, often referred to as motor coordination, is a fundamental skill that children develop during their school-age years. This ability to control and coordinate physical movements is crucial for a child's overall development and academic success. Research has shown that children with poor motor coordination, a condition known as developmental coordination disorder, often struggle with daily activities and academic achievement (Pérez & Coll, 2018). Motor skills, both fine and gross, are recognized as fundamental abilities that children should cultivate during their school years. Research has consistently shown that deficits in motor skills can have negative consequences on a child's academic performance and overall school success (Gidion, 2020). Previous studies have found that fine motor skills, particularly those involving visual-spatial integration such as copying tasks, are closely linked to various measures of academic achievement (Carlson et al., 2013). Researchers have found that the level of coordination abilities development is a crucial factor in determining the effectiveness of teaching motor actions (Hodges & Franks, 2002, Piccoli et al., 2018, Yu et al., 2015). This relationship between motor skills and cognitive processes has been extensively studied in the field of early childhood education and development. The relevance and practical value of researching kinesthetic sensitivity are highlighted in the works of (Li, Su, Fu, and Pickett 2015, Brink and Jacobs 2011). Kinaesthetic sensitivity, the awareness of one's body movement and position in space, and proprioception, the sense of limb position and body orientation, play a crucial role in the acquisition and refinement of motor skills (Thomas et al., 2008). The development of fine motor skills is closely linked to the maturation of small muscles in the fingers, wrists, and hands, as well as the coordination between the visual and motor systems. Purnama et al., (2020) Importantly, the development of fine motor skills does not occur in isolation, but is influenced by and interacts with other aspects of child development, including language and cognition. Through movement, children express themselves, and physical education programs provide physical health benefits for children, leading to more alertness in the classroom, as well as the development of self-image and a better understanding of their physical selves (Gunawan et al., 2023, Sadaruddin et al., 2022). The study of spatial abilities in the blind population has long been a topic of interest among researchers and scholars in the field of cognitive psychology and developmental science. While it was once believed that visual experience was a crucial factor in the development of spatial skills, a growing body of evidence suggests that the lack of visual input may have only limited effects on an individual's perception and mental representation of space (Bonino et al., 2015). Morash et al. (2012) found that data from their study on the spatial abilities of the blind underscore the importance of motor control indicators in the development of motor skills. Developing coordination abilities is a crucial aspect of education, as it not only enhances physical skills but also contributes to the overall cognitive and social development of students (Nilufar et al., 2023). One important element in this process is the availability of informative pedagogical control indicators, which can provide valuable insights into the progress and challenges faced by students (Pérez & Coll, 2018). Developmental coordination disorder is a condition characterized by significant difficulties in the acquisition and execution of coordinated motor skills, which can lead to academic challenges for affected children (Johnstone & García, 1994). Developing coordination abilities in students is a crucial aspect of education, and an essential element in this process is the availability of informative pedagogical control indicators and the knowledge of the peculiarities of teaching methods (Cochran et al., 1993). The methodology of pedagogical control incorporates a comprehensive approach by applying multidimensional mathematical and statistical methods of analysis. This approach, as detailed by Ivashchenko et al. (2018), allows for a more nuanced evaluation of educational processes and outcomes. Existing research has highlighted the multifaceted nature of motor control, involving the intricate interplay between various neural, sensory, and biomechanical systems (Hirschfeld, 2007). Muscular strength is a fundamental component of motor competence, which is crucial for schoolchildren's overall physical development and athletic performance (Radnor et al., 2020). Strength training and skill-based activities should be implemented in a progressive, developmentally appropriate manner to help build a positive association with physical activity (Rivilis et al., 2011). Gender-based differences in motor skill proficiency have also been observed, with girls generally demonstrating lower levels of fundamental motor skill proficiency compared to boys. This may stem from societal factors, as parents often encourage different skills in their children – girls are more likely to be encouraged in intellectual tasks, while boys are steered towards sports and physical activities (Whitehead, 2006). The proposed research study aims to address this gap by examining the unique considerations and challenges involved in assessing strength effort in young girls aged 10-12.

Materials and Methods

Study Participants

A total of 75 sedentary girls were randomly recruited from schools in the northeastern part of the region. Participants were selected based on criteria including a sedentary lifestyle, the absence of chronic illnesses, and no prior regular participation in structured exercise programs. Recruitment involved a randomized selection process from participating schools to ensure a representative sample.

Both participants and their guardians were fully informed about the study's objectives, procedures, potential risks, and benefits, and written informed consent was obtained from all participants and their parents or legal guardians.

Study Organization

This study utilized a descriptive design to assess the handgrip strength of sedentary girls across three different age groups: 10 years (n = 20), 11 years (n = 25), and 12 years (n = 30). The primary focus was on evaluating baseline handgrip strength without implementing any interventions. The paper used methods of scientific literature analysis, testing, and methods of mathematical statistics.

Testing Procedure

Strength Effort Assessment

Equipment: A calibrated handgrip dynamometer (model specified) was used for the measurement of maximum handgrip strength. A calculator was employed to determine the error percentage of the produced effort.

Testing: The maximum strength of the right hand was measured for each participant using a dynamometer. Considering the potential difference in the strength capabilities of girls, special care was taken to ensure that the girls felt comfortable and were encouraged to give their best effort.

After determining the maximum strength, the participants were asked to perform the following efforts, which correspond to:

- 1/3 of maximum strength;
- 1/2 of maximum strength;
- 2/3 of maximum strength.

Procedure

Each participant's maximum handgrip strength was measured on their dominant hand using the dynamometer. Participants were seated comfortably, with the elbow flexed at 90 degrees and the forearm in a neutral position during the measurement. The dynamometer handle was adjusted to fit the participant's hand size.

Testing Protocol

To determine the maximum handgrip strength, participants performed two attempts, with the highest value recorded as the maximum strength. Following this, participants were asked to exert efforts at 1/3, 1/2, and 2/3 of their maximum recorded strength. Each submaximal effort was performed once, and the result was documented in kilograms.

Ethical Considerations

The study adhered to ethical standards outlined in the 1964 Helsinki Declaration and its subsequent amendments. Special care was taken to ensure the psychological comfort of the participants, especially given their age and the nature of the physical tests. All participants were encouraged and motivated throughout the testing process to ensure maximum effort while minimizing stress or anxiety. Standard protocols were utilized to assess the parameters of interest.

Statistical Analysis

Statistical analyses were conducted using SPSS version 26. To evaluate the peculiarities of strength effort assessment, a t-test for paired observations and a t-test for independent samples were employed. These tests were used to compare the mean differences between different age groups and between various strength effort assessments within each age group. A significance level of $\alpha = 0.05$ was used for all statistical tests.

Results

Table 1 presents the results of the comparative analysis of strength effort assessment in girls aged 10 and 12. There are no statistically significant differences between these age groups in terms of hand maximum strength ($p = 0.709$) or strength effort at 1/3, 1/2, and 2/3 of maximum strength ($p > 0.05$). Both age groups show similar patterns in effort assessment, with no statistically significant differences observed. The girls demonstrate the highest assessment of effort at 1/3 of maximum strength (Table 1).

Table 2 displays the comparative analysis of strength effort assessment in girls aged 10 and 11. The analysis indicates no significant differences in hand maximum strength ($p = 0.755$) or effort at different percentages of maximum strength ($p > 0.05$). Similar to the previous table, both age groups exhibit comparable levels of strength effort assessment, with the best performance at 1/3 of maximum strength (Table 2). Table 3 provides a comparative analysis of strength effort assessment in girls aged 11 and 12. There are no statistically significant differences in hand maximum strength ($p = 0.704$) or effort at 1/3, 1/2, and 2/3 of maximum strength ($p > 0.05$). The results show that the highest assessment of effort occurs at 2/3 of maximum strength for both age groups (Table 3). Table 4 summarizes the analysis of strength effort assessment in girls aged 10. The results reveal a significant improvement in effort assessment at 1/2 compared to 1/3 of maximum strength ($p = 0.001$) and at 2/3 compared to 1/3 of maximum strength ($p = 0.000$). However, the difference between effort at 1/2 and 2/3 of maximum strength is not statistically significant ($p = 0.092$). These findings indicate a notable improvement in effort assessment as the percentage of maximum strength increases. Table 5 shows the analysis of strength effort assessment in girls aged 11. Significant differences are observed between effort at 1/2 and 1/3 of maximum strength ($p = 0.000$) and between effort at 2/3 and 1/3 of maximum strength ($p = 0.000$). Additionally, there is a significant difference between effort at 2/3 and 1/2 of maximum strength ($p = 0.031$). This suggests that girls aged 11 show improved assessment of effort as the percentage of maximum strength increases. Table 6 presents the analysis of strength effort assessment in girls aged 12. Significant differences are observed between effort at 1/2 and 1/3 of maximum strength ($p = 0.000$), effort at 2/3 and 1/3 of maximum strength ($p = 0.000$), and effort at 2/3 and 1/2 of maximum strength ($p = 0.002$). This indicates that girls aged 12 demonstrate a more pronounced improvement

Table 1. Comparative Analysis of Strength Effort Assessment in Girls Aged 10 and 12

Tests	Age	n	Mean	Std. Deviation	Mean Difference	t	p
Hand Maximum Strength	10	24	25.40	7.25	1.45	0.374	0.709
	12	30	26.85	6.85			
Effort at 1/3 of Maximum Strength, %	10	24	27.60	10.35	-1.24	-0.487	0.628
	12	30	28.84	9.75			
Effort at 1/2 of Maximum Strength, %	10	24	18.15	8.20	-0.84	-0.340	0.734
	12	30	19.00	7.85			
Effort at 2/3 of Maximum Strength, %	10	24	14.80	7.65	0.70	0.272	0.787
	12	30	14.10	7.05			

Table 2. Comparative Analysis of Strength Effort Assessment in Girls Aged 10 and 11

Tests	Age	n	Mean	Std. Deviation	Mean Difference	t	p
Hand Maximum Strength	10	24	25.40	7.25	0.85	0.313	0.755
	11	25	26.25	7.15			
Effort at 1/3 of Maximum Strength, %	10	24	27.60	10.35	-0.76	-0.273	0.785
	11	25	28.36	10.10			
Effort at 1/2 of Maximum Strength, %	10	24	18.15	8.20	-1.14	-0.447	0.658
	11	25	19.29	8.05			
Effort at 2/3 of Maximum Strength, %	10	24	14.80	7.65	1.05	0.371	0.713
	11	25	13.75	7.35			

Table 3. Comparative Analysis of Strength Effort Assessment in Girls Aged 11 and 12

Tests	Age	n	Mean	Std. Deviation	Mean Difference	t	p
Hand Maximum Strength	11	25	26.25	7.15	0.95	0.380	0.704
	12	30	26.85	6.85			
Effort at 1/3 of Maximum Strength, %	11	25	28.36	10.10	-0.94	-0.374	0.712
	12	30	29.30	9.75			
Effort at 1/2 of Maximum Strength, %	11	25	19.29	8.05	-0.65	-0.243	0.814
	12	30	19.94	7.85			
Effort at 2/3 of Maximum Strength, %	11	25	13.75	7.35	1.20	0.400	0.689
	12	30	14.95	7.05			

Table 4. Analysis of Strength Effort Assessment in Girls Aged 10 (n = 24)

Tests	Mean	Std. Error Mean	Difference	t	p
Pair 1: Effort at 1/3 vs. 1/2 of Maximum Strength (%)	27.60	2.10	9.45	4.250	0.001
Pair 2: Effort at 1/3 vs. 2/3 of Maximum Strength (%)	27.60	2.10	12.80	6.095	0.000
Pair 3: Effort at 1/2 vs. 2/3 of Maximum Strength (%)	18.15	1.95	3.35	1.718	0.092

Table 5. Analysis of Strength Effort Assessment in Girls Aged 11 (n = 25)

Tests	Mean	Std. Error Mean	Difference	t	p
Pair 1: Effort at 1/3 vs. 1/2 of Maximum Strength (%)	28.36	2.05	8.95	4.375	0.000
Pair 2: Effort at 1/3 vs. 2/3 of Maximum Strength (%)	28.36	2.05	13.00	6.320	0.000
Pair 3: Effort at 1/2 vs. 2/3 of Maximum Strength (%)	19.29	1.85	4.10	2.216	0.031

Table 6. Analysis of Strength Effort Assessment in Girls Aged 12 (n = 30)

Tests	Mean	Std. Error Mean	Difference	t	P
Pair 1: Effort at 1/3 vs. 1/2 of Maximum Strength (%)	29.00	1.87	8.50	4.545	0.000
Pair 2: Effort at 1/3 vs. 2/3 of Maximum Strength (%)	29.00	1.87	13.20	7.058	0.000
Pair 3: Effort at 1/2 vs. 2/3 of Maximum Strength (%)	21.05	1.84	6.10	3.318	0.002

in strength effort assessment at higher percentages of maximum strength.

Discussion

The study aimed to explore the peculiarities of strength effort assessment in girls aged 10, 11, and 12, focusing on their ability to gauge effort at various percentages of maximum strength. The findings indicate several key insights:

Age-Related Changes in Strength Effort Assessment: The study revealed that there are no significant age-related changes in the assessment of strength effort among girls aged 10 to 12. This suggests that the ability to assess effort at 1/3, 1/2, and 2/3 of maximum strength does not undergo significant development within this age range. This finding aligns with some previous research on motor development, which shows that certain aspects of motor abilities stabilize during these early developmental years.

Effort Assessment at 2/3 of Maximum Strength: Consistent with findings from previous studies on boys, girls aged 10 to 12 also demonstrated the most accurate assessment of effort at 2/3 of maximum strength. This result supports the data from Ivashchenko (2018) and Liakh (2000), which suggest that children and adolescents generally excel in evaluating efforts at higher percentages of their maximum strength. This trend underscores the relative stability and reliability of strength assessment at this level.

Differences in Effort Assessment Across Age Groups: Although no significant differences were found between age groups in the overall assessment of strength effort, specific findings highlight notable differences in the way girls assess effort at various levels. For instance, girls aged 10 showed significant differences in effort assessment between 1/3 and 1/2 of maximum strength, and between 1/3 and 2/3 of maximum strength. Similar patterns were observed in the assessments for girls aged 11 and 12. These results align with the notion that while the overall ability to assess strength may be stable, the precision of this assessment can vary across different effort levels and age groups.

The study's results highlight the importance of understanding and developing kinesthetic sensitivity among young girls. The observed patterns emphasize the need for targeted training programs that focus on improving the ability to assess and manage effort at various levels of strength. This aligns with the conclusions of previous studies suggesting that specialized training can enhance motor control and effort assessment abilities, as noted by Farfel (2011).

The findings contribute to the body of research on motor function development, particularly in the context of strength effort assessment. They extend the work of Li, Su, Fu, and Pickett (2015), Brink and Jacobs (2011), and Morash, Pensky, Alfaro, and McKerracher (2012) by providing new insights into how young girls assess strength effort and by underscoring the need for further research in this area. Our study on strength effort assessment in girls aged 10–12 revealed that, similar to the findings by Ivashchenko et al. (2019), there are no significant age-related differences in muscular effort assessment within this age range. Both studies found that the most accurate assessment of effort occurs at 2/3 of maximum strength, reflecting the stability of muscular control at this level. Additionally, neither study observed significant correlations between effort levels at 1/3, 1/2, and 2/3 of maximum strength, suggesting that errors in effort assessment are independent across these intensities. These results underscore the importance of focusing on strength assessment training at 2/3 of maximum strength and highlight the need for targeted interventions to improve effort assessment skills in young girls. By considering the interplay between motor skills, cognitive processes, and academic performance, researchers and educators can gain a more comprehensive understanding of the factors that contribute to the overall development and well-being of students (Carlson et al., 2013; Cameron et al., 2012). Educators must possess the necessary pedagogical competencies to effectively utilize technology in the learning environment, as it can significantly impact student achievement and motivation (Huda, 2019).

Conclusions

The study explored strength effort assessment among girls aged 10, 11, and 12, revealing that age does not significantly influence the ability to gauge effort at 1/3, 1/2, and 2/3 of maximum strength. Across all age groups, the most accurate assessment of effort was observed at 2/3 of maximum strength, indicating a consistent level of performance in this area. Although no significant differences in overall strength assessment were found between age groups, distinct patterns emerged in effort assessment at various levels. Specifically, significant differences in effort assessment were noted between 1/3 and 1/2 of maximum strength, and between 1/3 and 2/3 of maximum strength for girls aged 10, 11, and 12. These findings emphasize the stability of strength assessment capabilities within this age range while highlighting the need for targeted training programs to enhance precision in effort evaluation. The results contribute to a broader understanding of motor function development and underscore the importance of specialized interventions to improve strength effort assessment skills in young girls.

Conflict of Interest

The author declares no conflict of interest.

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Оцінка силових зусиль у дівчат передпідліткового віку: Аспекти точності визначення зусиль на різних порогових рівнях сили

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

Реферат. Стаття: 8 с., 6 табл., 33 джерела.

Мета дослідження. Метою цього дослідження було вивчити особливості оцінки силових зусиль у дівчат віком 10, 11 та 12 років. Зокрема, з'ясувати, яким чином у даних вікових групах визначається оцінка зусиль на рівні різних відсотків від максимальної сили (1/3, 1/2 та 2/3).

Матеріали та методи. У дослідженні взяли участь 75 дівчат, розподілених на три вікові групи: 10 років (n = 20), 11 років (n = 25) і 12 років (n = 30). За допомогою динамометра вимірювали максимальну силу кистей рук досліджуваних осіб, а також фіксували їхню здатність оцінювати зусилля на рівні 1/3, 1/2 і 2/3 від цього максимуму.

Результати. Похибка оцінки зусиль була розрахована та проаналізована з використанням t-критеріїв для парних та незалежних вибірок. Статистична значущість була встановлена на рівні α = 0,05. Аналіз не виявив суттєвих пов'язаних з віком відмінностей в оцінці максимальної сили кистей рук або силових зусиль між різними віковими групами. Найточніша оцінка зусиль відбувалася на рівні 2/3 від максимальної сили для всіх вікових груп. Значні відмінності встановлено в оцінці зусиль між 1/3 і 1/2 від максимальної сили, а також між 1/3 і 2/3 від максимальної сили, при цьому покращення показників відзначалося зі збільшенням відсотка зусиль. Однак значних відмінностей між показниками зусиль на рівні 1/2 і 2/3 від максимальної сили не спостерігалося.

Висновки. Дослідження показало, що здатність оцінювати силові зусилля у віковому діапазоні від 10 до 12 років залишається стабільною, а найточніша оцінка відбувається на рівні 2/3 від максимальної сили. Отримані дані вказують на той факт, що незважаючи на незмінний характер загальних здібностей щодо оцінки силових показників, цілеспрямовані тренування можуть підвищити точність визначення на різних рівнях зусиль. Це сприяє розумінню розвитку рухової функції та підкреслює необхідність впровадження інтервенцій з метою поліпшення навичок оцінки зусиль у юних дівчат.

Ключові слова: оцінка силових зусиль, руховий розвиток, юні дівчата, максимальна сила, кінестетична чутливість.

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Original Scientific Article

Using a Cross-Sectional Analysis of Age-Related Variations in Anthropometric Indices and their Association with Cardiometabolic Health in Adult Men

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Abstract

Background. Age-related changes in anthropometric indices and their association with cardiometabolic health markers are crucial for understanding health risks in adult men.

Objectives. The study aimed to assess age-related variations in anthropometric indices and their correlation with health markers, highlighting potential cardiometabolic health risks in adult men.

Materials and methods. A total of 200 men, aged 26 to 50 years, from Delhi-National Capital Region (NCR), India, were sampled using a multistage random sampling technique and divided into 5 age groups, each including 40 individuals. This study examined variations in body measurements such as the hip circumference (HC), waist circumference (WC), body mass index (BMI), and neck circumference (NC) across different age groups, as well as their relationship to health markers like HbA1c and lipid profile. Anthropometric measurements were taken in a standardized environment, and blood samples were taken under fasting conditions for lipid profile and HbA1c measurement. With SPSS software, descriptive statistics, a one-way ANOVA, and the Pearson correlation coefficients were used to analyze the data.

Results. Significant age-related differences were found in NC and WC, with NC increasing from 39.61 ± 2.53 cm to 41.20 ± 2.63 cm and WC rising from 89.68 ± 12.08 cm to 98.80 ± 9.90 cm, indicating a trend toward central obesity. BMI and HC showed no considerable variation across age groups. A one-way ANOVA revealed significant differences in NC ($F = 3.586$, $p = 0.008$) and WC ($F = 6.020$, $p = 0.005$). Pearson's correlations indicated that NC, BMI, and WC were positively correlated with triglycerides, LDL, and VLDL levels ($p < 0.05$), while no notable correlations were observed for HbA1c.

Conclusions. The study underscores the existence of significant age-related increases in NC and WC, suggesting heightened risks of abdominal obesity and cardiometabolic health issues in older men. Monitoring these anthropometric indices is vital for the early detection of health risks in adult males.

Keywords: adult men, anthropometric indices, cardiometabolic health, lipid profile, obesity.

Introduction

Anthropometric evaluations offer a practical and effective means of assessing the health and nutritional conditions of various demographic groups, demonstrating a significant correlation between these measurements and health, developmental, and socioeconomic factors (Beaton et al., 1990). As noted by De Onis and Blössner (2003), such studies help identify both under-nutrition and over-nutrition, which is critical for shaping health and nutrition policies. These indicators not only highlight the extent of nutritional issues but also provide a basis for ranking regions or populations by need, guiding the allocation of resources and interventions. Increasingly, attention has been directed toward evaluating body fat distribution, overweight, and obesity, given their association with the increased incidence of chronic illnesses, particularly among adults (Seidell et al., 2001). Anthropometric indicators, including waist circumference (WC) and body mass index (BMI) are now

recognized as essential tools in clinical and public health settings for assessing men's health and their risk of chronic diseases (World Health Organization, 1995).

While BMI remains a widely used indicator in public health assessments, it has notable limitations. BMI does not distinguish between lean mass and fat mass, which can be misleading in assessing individuals with high muscle mass or varying body compositions. As a result, there has been a shift toward using alternative anthropometric measures such as WC, which provide more detailed insights into fat distribution and its related risks to health (National Heart, Lung, and Blood Institute, 2023). Because central obesity, especially abdominal fat, is strongly associated with metabolic disorders such insulin resistance, lipid disorders, and hypertension, it is regarded as a serious health concern (Ashwell et al., 2012). Studies indicate that males are more likely than women to develop visceral fat, which dramatically increases the chance of metabolic along with cardiovascular disorders (Kahn et al., 2019). Insulin resistance and inflammatory processes are linked to this buildup of abdominal fat, both of which contribute to chronic diseases, making it essential to assess the correlation between anthropometric indices and health markers like lipid profiles and glycemic control.

The growing prevalence of obesity, particularly among men, has significant health implications. It is widely known that obesity poses a significant risk for non-communicable diseases (NCDs), such as cardiovascular disease and type II diabetes, which are the two biggest causes of death and morbidity globally. In India, estimated 62 million people exhibit traits associated with obesity, increasing their vulnerability to these diseases (Mohan & Deepa, 2015). One of the primary drivers behind the rise in NCDs is physical inactivity, which has become a global concern in the fight against these illnesses (Beaglehole et al., 2011; Lee et al., 2012). Health indicators such as triglycerides, low-density lipoprotein (LDL), high-density lipoprotein (HDL), and HbA1c levels are crucial for evaluating cardiometabolic risk. The risk of cardiovascular illnesses are increased by high LDL and low HDL values, while high HbA1c levels reflect poor glycemic control, indicating a heightened risk of type IIdiabetes (American Heart Association, 2022). Studies show that individuals with higher waist circumferences often have adverse lipid profiles and elevated HbA1c levels, further linking central obesity to negative metabolic outcomes (Kahn et al., 2019). This is particularly concerning for adult men, who may exhibit higher cardiometabolic risks due to the shifts in body composition brought on by aging.

Urbanization, lifestyle changes, and dietary shifts in regions like Delhi-NCRhave contributed to a rising trend in obesity among men, with significant consequences for public health. According to a research by Kalra et al. (2021), one in four people in India are obese, with the greatest percentages of body fat among men and women seen in cities like Delhi. The NCD Risk Factor Collaboration (2016) found that from 0.5 % in 1990 to 5.4 % in 2022, Indian men's obesity prevalence increased significantly. In addition, the National Family Health Survey (NFHS-5), which was carried out in 2019 and 2021, discovered that during the previous 15 years, the overall incidence of overweight and obesity among males aged 15 to 49 years has increased from 9.3 % to 22.9 % (Iips, 2021). Given that NCDs like diabetes and cardiovascular disease—which are now India's top causes of death and morbidity—have a significant correlation with obesity, the fast rise in obesity is concerning.

Men in urban areas, particularly those in Delhi-NCR, are particularly susceptible to these health risks. The region has experienced rapid urbanization and lifestyle changes, including sedentary behavior, poor dietary habits, and reduced physical activity, all of which have an increasing impact on the incidence of obesity and related illnesses. According to research, visceral fat is more common in adult males. This fat is highly linked to a higher risk of the metabolic syndrome along with cardiovascular illnesses (Kahn et al., 2014). As central obesity becomes more prevalent, assessing the correlation between anthropometric indices such as WC, and other health markers like lipid profiles and glycemic control becomes critical for identifying individuals at risk of developing chronic diseases.

Experts emphasize the importance of making lifestyle changes, including making better dietary choices and getting regular exercise, to combat the obesity pandemic and reduce the associated health risks (Gulati & Misra, 2017). Despite the widespread use of anthropometric measurements in public health assessments, significant gaps remain in understanding how these indices specifically impact adult men in urban settings like Delhi-NCR. Current research often aggregates data across genders and age groups, overlooking the socio-cultural and economic factors that uniquely influence health in adult men (Aggarwal et al., 2021). Also, a large portion of the study that has already been done has been on young people and adolescents., leaving a critical gap in knowledge regarding adult males, who face higher risks of cardiometabolic conditions (Devi et al., 2020). Addressing these gaps is necessary in order to create focused public health programs that address the unique health requirements of this population.

This study aims to address these gaps by investigating age-related variations in anthropometric indices and their associations with cardiometabolic health markers in adult men from Delhi-NCR. By focusing on key indices such as BMI and WC, this research seeks to provide a clearer understanding of how body composition changes with age and how these changes relate to metabolic and cardiovascular risks. Additionally, this study will evaluate the effectiveness of these indices in predicting cardiometabolic diseases in this population. The findings will offer valuable insights into improving screening practices and health promotion strategies tailored to the needs of adult men in urban environments, contributing to more efficient healthcare initiatives meant to lessen the burden of non-communicable diseases.

Methods and Materials

Study Participants

The study involved a sample of adult males aged 26 to 50 years residing in Delhi and the National Capital Region (NCR), India. A multistage random sampling technique was employed to ensure a representative sample, stratified into five age groups: 26-30, 31-35, 36-40, 41-45, and 46-50 years. Inclusion criteria required participants to be healthy male adults who had been residing in the region for a minimum

of a year. Among the exclusion standards were individuals with recent surgeries, chronic illnesses, or conditions such as diabetes and cardiovascular diseases that could affect the anthropometric indices and health markers being measured. Ultimately, 200 participants were recruited, with 40 individuals from each age group, and everyone provided written, informed consent.

Study Organization

Standardization in data collecting processes was ensured by the controlled setting in which the study was performed. Anthropometric measures were obtained with calibrated equipment, including Neck Circumference (NC), Waist Circumference (WC), Hip Circumference (HC), and Body Mass Index (BMI). NC was measured to the closest 0.1 cm using a flexible measuring tape at the point directly below the Adam's apple, making that the tape was tight but did not compress the skin.

The formula used to determine BMI was (BMI = Weight (kg) / Height $(m)^2$), where weight was recorded to the closest 0.1 kg and 0.1 cm, respectively, using a calibrated weighing scale along with height measured using a stadiometer. The narrowest point on the torso, usually just above the navel, was used to measure WC. The tape was positioned tightly without squeezing the skin, and the measurements were taken to the closest 0.1 cm. The widest point of the hips was used to measure HC. The tape was positioned parallel to the floor, tight but without squeezing the skin and the measurement was taken to the closest 0.1 cm.

Samples of the blood were collected early in the morning after an overnight fast from various locations in Delhi, India, including IGIPESS Vikaspuri (25 samples), Gurgaon Sector 40 (62 samples), Batla House, Jamia Nagar (50 samples), and Lajpat Nagar (33 samples) and Shalimar Bagh (30 samples), and analyzed at Indo-Arab Diagnostic in Gurgaon for HbA1c and lipid profile (Triglycerides (TGL), Low Density Lipoprotein (LDL), High Density Lipoprotein (HDL), Very Low Density Lipoprotein (VLDL).

Data collection was supervised by trained researchers to maintain consistency and accuracy throughout the process, and blood samples were analyzed at the Modern Diagnostic and Research Lab, Gurgaon, where testing was conducted by certified technicians from the lab.

Statistical Analysis

SPSS software was used for data analysis. For every anthropometric index and health marker, descriptive statistics were computed, such as means and standard deviations. To compare the means of the five age groups, a one-way ANOVA was used; the Tukey post-hoc test was then used to identify any differences between the groups. Anthropometric indices and health markers were compared using Pearson's correlation coefficient, which shed light on possible links and health hazards. To guarantee the dependability of the findings, a significance threshold of 0.05 was established for every statistical test.

Results

Table 1 summarizes the mean values and standard deviations of key anthropometric indices—NC, BMI, WC, and HC—across five age groups of adult men (26-30, 31-35, 36-40, 41-45, and 46-50 years), with each group comprising 40 participants. The data reveal a gradual increase in NC from 39.61 ± 2.53 cm in the youngest group to 41.20 ± 2.63 cm in the oldest group, alongside a rise in BMI from 25.09 ± 5.02 kg/m^2 to 26.82 ± 4.65 kg/m^2, indicating a potential trend towards higher body weight with age. WC also exhibited a significant increase, from 89.68 ± 12.08 cm to 98.80 ± 9.90 cm, suggesting a greater risk of abdominal obesity among older participants. In contrast, HC remained relatively stable across age groups, ranging from 100.41 ± 9.80 cm to 102.48 ± 7.27 cm. These findings highlight important age-related trends in anthropometric measurements that may have implications for assessing cardiometabolic health risks in adult men.

Table 2 presents the mean values and standard deviations of various health markers, including HbA1c, TGL, LDL, HDL, and VLDL, across five age groups of adult men (26-30, 31-35, 36-40, 41-45, and 46-50 years), with each group consisting of 40 participants. The mean HbA1c levels ranged from 5.33 ± 6.48 % in the 36-40 years age group to 5.61± 4.92 % in the 46-50 years age group, indicating a slight increase in glycemic control with age. TGL levels showed variability, with the highest mean observed in the 31-35 years group at 132.75 ± 30.90 mg/dL, while the lowest was in the 36-40 years group at 120.15 ± 35.52 mg/dL. LDL levels ranged from 93.50 ± 24.18 mg/dL in the 31-35 years group to 102.00 ± 19.33 mg/dL in the 41-45 years group, suggesting fluctuations in lipid profiles across age groups. HDL levels remained relatively stable, ranging from 40.18 ± 4.89 mg/dL in the 31-35 years group to 42.15 ± 5.70 mg/dL in the 46-50 years group. VLDL levels also exhibited slight variations, with a range from 21.48 ± 7.13 mg/dL in the 36-40 years group to 23.77 ± 6.69 mg/dL in the 31-35 years group. These results highlight the need of tracking health indicators across several age groups to detect possible metabolic health problems and cardiovascular risks in adult males.

Table 3 provides a summary of the one-way ANOVA results for the anthropometric variables (NC, BMI, WC, and HC) across different age groups of adult men. The analysis

Table 1. Descriptive summary of anthropometric indices by age group in adult men

Age (yr)	n	NC (cm)	BMI (kg/m^2)	WC (cm)	HC (cm)
26-30	40	39.61 ± 2.53	25.09 ± 5.02	89.68 ± 12.08	100.41 ± 9.80
31-35	40	39.89 ± 2.70	26.35 ± 4.34	94.00 ± 10.55	101.58 ± 8.47
36-40	40	41.01 ± 1.97	26.98 ± 4.30	96.56 ± 8.95	102.48 ± 7.27
41-45	40	41.04 ± 2.47	27.12 ± 2.92	98.75 ± 7.25	101.43 ± 6.77
46-50	40	41.20 ± 2.63	26.82 ± 4.65	98.80 ± 9.90	101.38 ± 8.61

Table 2. Descriptive summary of health markers by age group in adult men

Age (yr)	N	HbA1c (%)	TGL (mg/dL)	LDL (mg/dL)	HDL (mg/dL)	VLDL (mg/dL)
26-30	40	5.46 ± 6.48	127.88 ± 36.83	101.39 ± 22.89	42.15 ± 4.42	22.45 ± 6.80
31-35	40	5.60 ± 5.20	132.75 ± 30.90	93.50 ± 24.18	40.18 ± 4.89	23.77 ± 6.69
36-40	40	5.33 ± 4.77	120.15 ± 35.52	97.93 ± 18.90	41.38 ± 4.63	21.48 ± 7.13
41-45	40	5.46 ± 2.56	131.13 ± 34.94	102.00 ± 19.33	41.25 ± 4.88	22.27 ± 8.11
46-50	40	5.61 ± 4.92	128.15 ± 35.70	96.32 ± 19.87	42.15 ± 5.70	22.69 ± 7.56

Table 3. Summary of one-way ANOVA of anthropometric variables among age groups in adult men

Variables	Source of Variation	Sum of Squares	Df	Mean Square	F-value	p-value
NC	Between Groups	87.675	4	21.919	3.586	.008
	Within Groups	1191.825	195	6.112		
BMI	Between Groups	108.583	4	27.146	1.464	.215
	Within Groups	3616.036	195	18.544		
WC	Between Groups	2349.820	4	587.455	6.020	.005
	Within Groups	19027.769	195	97.578		
HC	Between Groups	85.955	4	21.489	.316	.867
	Within Groups	13277.344	195	68.089		

*. Significant at 0.05 level

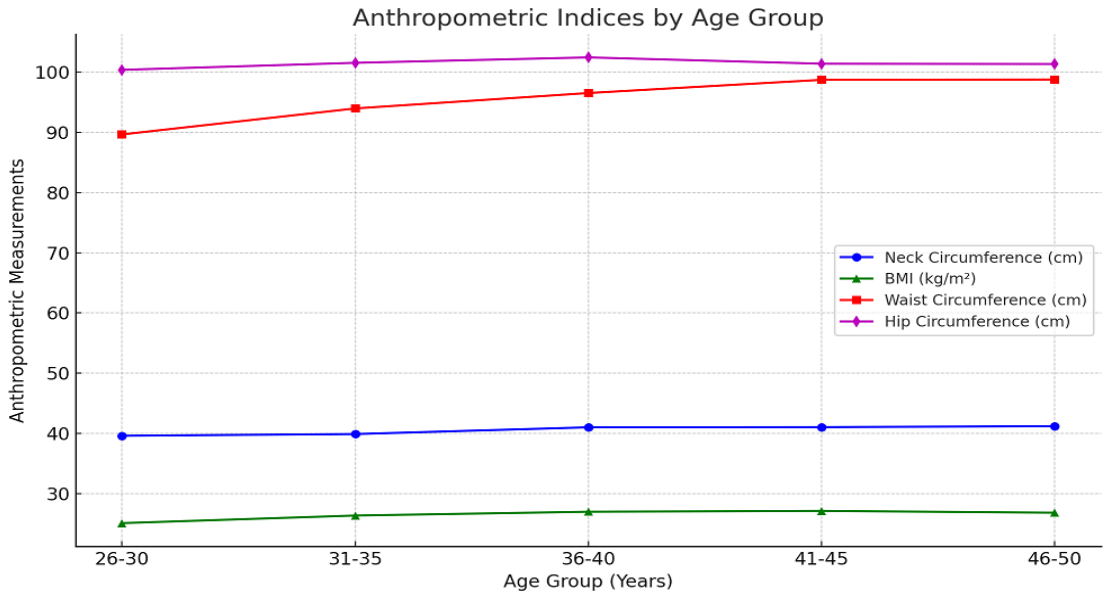

Fig. 1. Age-related trends in anthropometric indices among adult men

was conducted to determine whether significant differences exist in these measurements between the five age groups (26-30, 31-35, 36-40, 41-45, and 46-50 years). The findings indicate that both NC and WC show statistically significant differences across age groups.

For NC, the between-group variation was significant, with a p-value of .008 and an F-value of 3.586, implying that as men age, noticeable differences in NC are observed. This could reflect changes in fat distribution and upper body adiposity, which are known to vary with age.

Similarly, WC displayed a significant difference across age groups, as evidenced by a p-value of .005 and an F-value of 6.020. This finding is particularly relevant, as WC is closely associated with abdominal fat, a known risk factor for metabolic syndrome and cardiovascular diseases. The significant increase in WC with age may indicate a heightened risk of these conditions in older age groups.

In contrast, BMI did not show significant variation among age groups, with a p-value of .215 and an F-value of 1.464. Despite BMI being a widely used measure of overall body fat, this result suggests that BMI alone may not fully capture the age-related changes in body composition, particularly fat distribution.

Similarly, HC also did not show significant differences between age groups, as indicated by a p-value of .867 and an F-value of .316, suggesting that HC remain relatively stable with age.

Overall, these findings suggest that while certain anthropometric indices such as NC and WC vary significantly with age, others like BMI and HC may remain more constant.

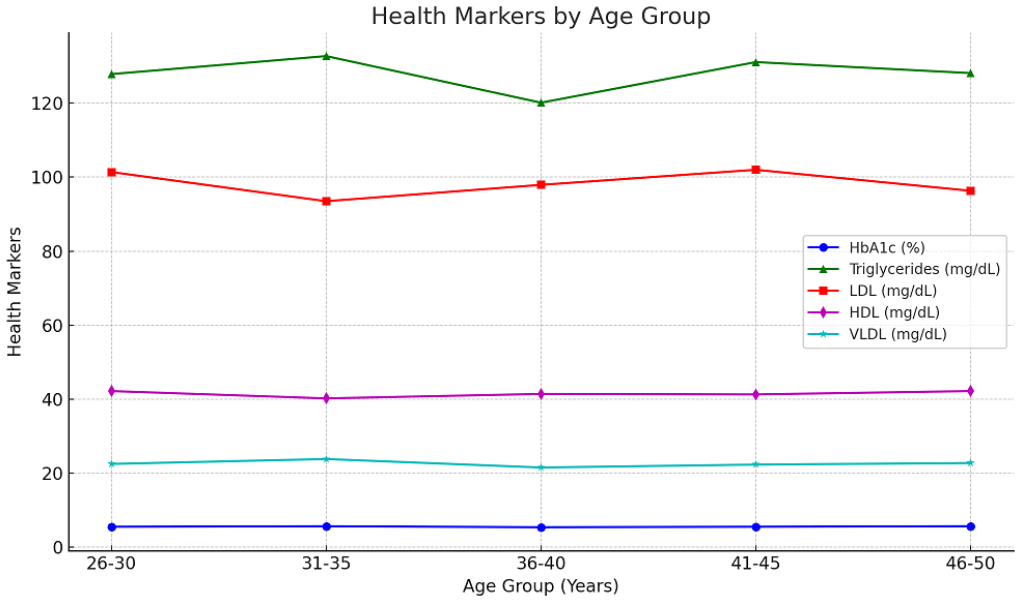

Fig. 2. Variation in health markers by age group in adult men

These results highlight the importance of focusing on specific body measurements, such as neck and waist circumferences, when assessing age-related changes in body composition and the associated health risks in adult men.

Table 4 provides a summary of the one-way ANOVA results for health markers (HbA1c, TGL, LDL, HDL, and VLDL) across different age groups of adult men. The analysis was conducted to determine whether significant differences exist in these health markers between the five age groups (26-30, 31-35, 36-40, 41-45, and 46-50 years). The findings indicate that none of the health markers displayed statistically significant differences across age groups.

For HbA1c, the analysis revealed a p-value of 0.636 and an F-value of 0.638, indicating that there are no significant variations in glycemic control among the different age groups. This suggests that HbA1c levels remain relatively stable across the ages studied, implying that age may not significantly impact long-term glucose levels in this population.

Similarly, TGL did not show significant differences across age groups, with a p-value of 0.543 and an F-value of 0.775. This result indicates that TGL levels are consistent among the age groups, suggesting that factors other than age may play a more critical role in influencing TGL levels in adult men.

The LDL levels also exhibited no significant variation, as evidenced by a p-value of 0.346 and an F-value of 1.125. This finding implies that age may not be a significant determinant of LDL cholesterol levels in this cohort, highlighting the need for other risk factors to be considered when assessing cardiovascular risk.

For HDL, the results showed a p-value of 0.411 and an F-value of 0.996, indicating that there are no significant differences in HDL levels among the age groups. This stability in HDL levels suggests that age-related changes in lipid profiles may not be as pronounced in this population.

Lastly, VLDL levels also did not demonstrate significant differences, with a p-value of 0.724 and an F-value of 0.516.

Table 4. Summary of one-way ANOVA of health markers among age groups in adult men

Variables	Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
HbA1c	Between Groups	2.167	4	.542	.638	.636
	Within Groups	165.477	195	.849		
TGL	Between Groups	3759.530	4	939.882	.775	.543
	Within Groups	236638.450	195	1213.531		
LDL	Between Groups	2011.635	4	502.909	1.125	.346
	Within Groups	87141.033	195	446.877		
HDL	Between Groups	96.630	4	24.158	.996	.411
	Within Groups	4728.725	195	24.250		
VLDL	Between Groups	109.411	4	27.353	.516	.724
	Within Groups	10328.733	195	52.968		

*. Significant at 0.05 level

Table 5. Pairwise comparison of NC and WC among age groups of 26-30, 31-35, 36-40, 41-45, and 46-50 in adult men

Variables	(I) order	(J) order	Mean Difference (I-J)	Std. Error	Sig.	95 % Confidence Interval	
						Lower Bound	Lower Bound
NC	1.0	2.0	-.2750	.5528	.988	-1.797	1.247
		3.0	-1.4000	.5528	.088	-2.922	.122
		4.0	-1.4250	.5528	.079	-2.947	.097
		5.0	-1.5875*	.5528	.036	-3.110	-.065
	2.0	3.0	-1.1250	.5528	.253	-2.647	.397
		4.0	-1.1500	.5528	.233	-2.672	.372
		5.0	-1.3125	.5528	.127	-2.835	.210
	3.0	4.0	-.0250	.5528	1.000	-1.547	1.497
		5.0	-.1875	.5528	.997	-1.710	1.335
	4.0	5.0	-.1625	.5528	.998	-1.685	1.360
WC	1.0	2.0	-4.3250	2.2088	.291	-10.407	1.757
		3.0	-6.8875*	2.2088	.018	-12.969	-.806
		4.0	-9.0750*	2.2088	.001	-15.157	-2.993
		5.0	-9.1250*	2.2088	.001	-15.207	-3.043
	2.0	3.0	-2.5625	2.2088	.774	-8.644	3.519
		4.0	-4.7500	2.2088	.203	-10.832	1.332
		5.0	-4.8000	2.2088	.194	-10.882	1.282
	3.0	4.0	-2.1875	2.2088	.859	-8.269	3.894
		5.0	-2.2375	2.2088	.849	-8.319	3.844
	4.0	5.0	-.0500	2.2088	1.000	-6.132	6.032

Key: 1.0: Age group 26-30; 2.0: Age group 31-35; 3.0: Age group 31-35; 4.0: Age group 36-40; 5.0: Age group 46-50

This finding reinforces the notion that VLDL levels remain relatively constant across different age groups, indicating that age may not be a critical factor in determining VLDL concentrations in adult men.

Overall, these findings suggest that health markers such as HbA1c, TGL, LDL, HDL, and VLDL do not vary significantly with age in adult men. This stability implies that while age may influence certain health outcomes, these specific markers may be more influenced by other factors, such as lifestyle, diet, and genetic predispositions. Therefore, it is essential to consider a broader range of factors when assessing cardiovascular and metabolic health risks in adult men, rather than relying solely on age-related changes in these health markers.

A Tukey post hoc test was conducted to measure the significant differences between the groups. The results, as shown in the table 5 presents the pairwise comparisons for NC and WC among different age groups of adult men (26-30, 31-35, 36-40, 41-45, and 46-50 years). The analysis aims to identify significant differences in these anthropometric measurements across the specified age groups. For NC, the findings reveal a significant difference between the youngest (26-30 years) and oldest (46-50 years) age groups, with men aged 46-50 years having a significantly lower NC compared to those aged 26-30 years (mean difference -1.5875, $p = 0.036$). This suggests that age may influence NC, possibly reflecting changes in body composition and fat distribution with advancing age. However, other comparisons for NC did not yield statistically significant results. In contrast, the pairwise comparisons for WC revealed several significant differences. Men aged 36-40 years had a significantly larger WC compared to those aged 26-30 years (mean difference -6.8875, $p = 0.018$), and similar significant increases were observed in the 41-45 and 46-50 age groups. These findings underscore the importance of monitoring WC as a key indicator of health risks associated with aging in adult men, given that WC is closely associated with abdominal fat and is a known risk factor for metabolic syndrome and cardiovascular diseases. The results also suggest that as men age, their WC tends to increase significantly, while NC may not be as sensitive to age-related changes.

This table 6 presents the Pearson correlation coefficients and their corresponding significance levels (2-tailed) between various anthropometric indices and health markers in a sample of adult men. The anthropometric indices include NC, BMI, WC, and HC, while the health markers consist of HbA1c, TGL, LDL, HDL, and VLDL.

The results show that NC is significantly and positively correlated with BMI ($r = 0.714$, $p < 0.01$), WC ($r = 0.688$, $p < 0.01$), and HC ($r = 0.656$, $p < 0.01$), indicating that as NC increases; these other anthropometric measures also tend to increase. This suggests that NC may be a useful indicator of overall body composition and fat distribution in adult men.

BMI is also significantly correlated with WC ($r = 0.765$, $p < 0.01$) and HC ($r = 0.694$, $p < 0.01$), highlighting the re-

Table 6. Pearson correlation matrix of anthropometric indices and health markers in adult men

Variables	r	NC	BMI	WC	HC	HbA1C	TGL	LDL	HDL	VLDL
BMI	r	.714**	1							
WC	r	.688**	.765**	1						
HC	r	.656**	.694**	.800**	1					
HbA1c	r	.051	.027	.070	.027	1				
TGL	r	.177*	.157*	.147*	.122	.398**	1			
LDL	r	.253**	.182*	.125	.153*	.241**	.563**	1		
HDL	r	.062	.105	.056	.109	-.007	-.025	.163*	1	
VLDL	r	.172*	.143*	.120	.124	.352**	.697**	.474**	.039	1

*. Correlation is significant at the 0.05 level (two-tailed), **. Correlation is significant at the 0.01 level (two-tailed)

lationship between BMI and body size measurements. WC and HC are strongly correlated with each other ($r = 0.800$, $p < 0.01$), which is expected as they both measure aspects of body size and shape.

Regarding the health markers, HbA1c does not show significant correlations with any of the anthropometric indices, suggesting that glycemic control may be influenced by factors other than body measurements in this population.

However, TGL exhibits significant positive correlations with NC ($r = 0.177$, $p < 0.05$), BMI ($r = 0.157$, $p < 0.05$), and WC ($r = 0.147$, $p < 0.05$), implying that higher levels of TGL are associated with larger NC, BMI, and WC. LDL is significantly correlated with NC ($r = 0.253$, $p < 0.01$), BMI ($r = 0.182$, $p < 0.05$), and HC ($r = 0.153$, $p < 0.05$), suggesting that LDL levels may be influenced by certain body measurements.

HDL shows a significant positive correlation only with LDL ($r = 0.163$, $p < 0.05$), while VLDL is significantly correlated with NC ($r = 0.172$, $p < 0.05$), BMI ($r = 0.143$, $p < 0.05$), and both TGL ($r = 0.697$, $p < 0.01$) and LDL ($r = 0.474$, $p < 0.01$).

These findings highlight the complex relationships between anthropometric indices and cardiometabolic health markers in adult men. The significant correlations observed, particularly between NC and measures of overall and central adiposity; underscore the potential utility of NC as a simple, non-invasive tool for assessing cardiometabolic risk in this population. However, further research is needed to establish the predictive ability of NC and other anthropometric measures in relation to clinical outcomes.

Discussion

The results of this study provide critical insights into the age-related changes in anthropometric indices and their implications for cardiometabolic health in adult men. A significant increase in neck circumference (NC) and waist circumference (WC) across age groups highlights the potential for these measurements to serve as markers of age-related fat distribution, particularly in upper body and abdominal regions. The observed rise in NC, from 39.61 ± 2.53 cm in the 26-30 years group to 41.20 ± 2.63 cm in the 46-50 years group, suggests a shift in fat deposition with age, possibly due to changes in body composition and adiposity patterns (Ponti et al., 2020; Kuk et al., 2009). Similarly, WC showed a marked increase from 89.68 ± 12.08 cm to 98.80 ± 9.90 cm, indicating a growing risk of abdominal obesity as men age, which is a well-established risk factor for metabolic syndrome and cardiovascular diseases (Goh & Hart, 2016).

Interestingly, body mass index (BMI) did not show significant differences across age groups ($p = 0.215$), despite the significant changes in NC and WC. This suggests that BMI, though widely used, may not be sensitive enough to detect age-related changes in body composition, particularly in fat distribution. In contrast, NC and WC, which were found to vary significantly with age ($p = 0.008$ and $p = 0.005$, respectively), could serve as more reliable indicators of health risks associated with aging in men (Shen et al., 2006; Saka et al., 2014; Ben-Noun et al., 2001). The lack of variation in hip circumference (HC) across age groups further supports this, as HC remained relatively stable, indicating that central obesity, rather than general body size, may be the more concerning issue in older men (Whitmer et al., 2008).

The health markers—HbA1c, triglycerides, LDL, HDL, and VLDL—did not display statistically significant differences across age groups, suggesting that age alone may not substantially impact these markers in this population. For example, HbA1c levels showed minimal fluctuation ($p = 0.636$), which implies that glycemic control remains stable across different ages, potentially influenced more by factors such as diet, physical activity, and genetics rather than age alone (Yardley et al., 2018). However, the significant correlations between NC, BMI, WC, and certain health markers, such as triglycerides and LDL, suggest that as anthropometric indices increase, so do these cardiometabolic risk factors. Specifically, NC showed positive correlations with both BMI and WC ($r = 0.714$ and $r = 0.688$, respectively), reinforcing the role of NC as a potential surrogate marker for overall adiposity and cardiovascular risk (Arias Téllez, 2020; Onat et al., 2009; Androutsos et al., 2012).

The findings from the post hoc analysis further emphasize the importance of waist circumference in assessing health risks, as significant differences were found between age groups, particularly between men aged 26-30 and those aged 36-40 and above. This highlights the need for targeted interventions to address abdominal obesity, especially in older populations where WC is closely linked to increased risk for metabolic syndrome and cardiovascular diseases (Després, 2006; Després et al., 2008; Shirai, 2004). In contrast, NC, while useful, may not be as sensitive to changes within shorter age intervals, despite showing significant differences between the youngest and oldest age groups.

Conclusions

This study underscores the importance of focusing on NC and WC, rather than solely relying on BMI, for assessing cardiometabolic health risks in aging men. These measures, particularly WC, should be considered in routine health assessments to better identify those who run the risk of developing abdominal obesity and the related health consequences. While the stability of key health markers across age groups suggests that aging alone may not drive metabolic deterioration, the correlations between anthropometric indices and certain cardiometabolic markers highlight the complex interplay between body composition and health outcomes. To investigate the long-term impacts of variations in NC and WC on long-term health concerns, more investigation is necessary.

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Conflicts of Interest

No conflicts of interest are disclosed by authors.

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Застосування поперечного аналізу щодо вікових змін антропометричних показників та їх взаємозв'язку з кардіометаболічним здоров'ям у дорослих чоловіків

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

Реферат. Стаття: 10 с., 6 табл., 2 рис., 30 джерел.

Історія питання. Вікові зміни антропометричних показників та їх взаємозв'язок з маркерами кардіометаболічного стану мають вирішальне значення в контексті розуміння ризиків для здоров'я дорослих чоловіків.

Мета дослідження. Мета дослідження полягала в оцінці вікових змін антропометричних показників та їх кореляції з маркерами здоров'я, а також у висвітленні потенційних кардіометаболічних ризиків для здоров'я дорослих чоловіків.

Матеріали та методи. Загалом 200 чоловіків у віці від 26 до 50 років з Національного столичного регіону (НСР) м. Делі (Індія) було відібрано за методом багатоступеневої рандомізації та розподілено на 5 вікових груп, кожна з яких включала по 40 осіб. В рамках цього дослідження вивчалися варіації таких параметрів тіла, як окружність стегон (ОС), окружність талії (ОТ), індекс маси тіла (ІМТ) та окружність шиї (ОШ) у різних вікових групах, а також зв'язок зазначених показників з такими маркерами стану здоров'я, як рівень глікозильованого гемоглобіну (HbA1c) та ліпідний профіль. Антропометричні вимірювання проводилися в стандартизованих умовах, а зразки крові для визначення показників ліпідного профілю та HbA1c відбиралися натщесерце. З метою аналізу даних використовували описову статистику, однофакторний дисперсійний аналіз (ANOVA) та коефіцієнти кореляції Пірсона за допомогою програмного забезпечення SPSS.

Результати. Встановлено достовірні вікові відмінності в показниках ОШ та ОТ, а саме: підвищення параметрів ОШ з 39,61 ± 2,53 см до 41,20 ± 2,63 см та ОТ з 89,68 ± 12,08 см до 98,80 ± 9,90 см, що вказує на тенденцію до ожиріння центрального типу. Показники ІМТ та ОС не мали значних відмінностей між віковими групами. Односторонній дисперсійний аналіз виявив суттєві відмінності в показниках ОШ ($F = 3,586$, $p = 0,008$) та ОТ ($F = 6,020$, $p = 0,005$). Кореляції Пірсона свідчать про позитивне співвідношення параметрів ОШ, ІМТ та ОТ з рівнями тригліцеридів, ліпопротеїдами низької щільності (ЛПНЩ) та ліпопротеїдами дуже низької щільності (ЛПДНЩ) ($p < 0,05$), тоді як для показника HbA1c не спостерігалося жодних суттєвих кореляційних зв'язків.

Висновки. Дослідження підкреслює наявність значних вікових збільшень показників ОШ та ОТ, що свідчить про підвищений ризик абдомінального ожиріння та кардіометаболічних патологій у чоловіків старшого віку. Моніторинг зазначених антропометричних показників є важливим чинником щодо ранньої діагностики ризиків для здоров'я дорослих чоловіків.

Ключові слова: дорослі чоловіки, антропометричні показники, кардіометаболічне здоров'я, ліпідний профіль, ожиріння.

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Original Scientific Article

Determining the Correlation of Fat-Free Mass, Power, and Maximum Hamstring Force in Female Basketball Athletes

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Abstract

Background. In competitive sports, especially basketball, physical attributes such as agility, speed, strength, and power are crucial for performance.

Objectives. This study aimed to examine the correlation between fat-free mass (FFM), countermovement jump (CMJ) power, and maximum hamstring force in female basketball athletes, providing insights that could enhance performance and reduce injury risk.

Materials and methods. This observational cross-sectional study investigates the relationship between fat-free mass (FFM), power, and maximum hamstring force in 45 female basketball athletes. The Anderson-Darling test for assessing normality and Spearman's correlation for non-normally distributed data were used to conduct the study.

Results. Significant correlations were found between FFM and maximum hamstring force in the both right ($r = 0.585$, $p < 0.001$) and left legs ($r = 0.522$, $p < 0.001$), as well as between (CMJ) power and maximum hamstring force for both legs (right: $r = 0.467$, $p = 0.001$; left: $r = 0.434$, $p = 0.003$). Additionally, power was significantly correlated with jump height ($r = 0.604$, $p < 0.001$).

Conclusions. These findings suggest that FFM and power are critical determinants of hamstring strength and explosive performance in female basketball athletes.

Keywords: fat-free mass, hamstring force, power, correlation, female basketball athletes.

Introduction

The level of female participation in basketball has been on the rise, reflecting growing interest and enthusiasm for the sport among women. Despite this positive trend, there remains a significant gap between the ideal physical attributes desired in basketball and the current state of female participation. Women in basketball often face several challenges, including limited access to high-quality training facilities, societal stereotypes, and less media coverage compared to their male counterparts (Bell et al., 2014). These obstacles can hinder the development and recognition of female athletes. Nevertheless, the benefits of participating in basketball for women are profound. The sport enhances physical fitness, cardiovascular health, and muscle strength. It also fosters teamwork, leadership skills, and self-confidence, contributing significantly to personal and professional growth. Additionally, the increasing visibility of women's basketball at the collegiate and professional levels has created more opportunities for scholarships and careers, encouraging more young women to pursue the sport seriously (Petridis et al., 2019).

Understanding the factors that contribute to athletic performance in female basketball players is crucial for optimizing training and reducing injury risks. Data indicates that specific physical attributes, such as fat-free mass (FFM), coun-

termovement jump (CMJ) power, and maximum hamstring force, play pivotal roles in performance outcomes. For example, an analysis of WNBA players' profiles revealed that athletes with higher CMJ power had significantly better performance metrics (Heishman et al., 2020). Diana Taurasi, one of the top WNBA players, exhibits exceptional CMJ power, which correlates with her ability to achieve high jump heights and explosive movements on the court. This correlation between CMJ power and performance highlights the importance of explosive strength in basketball. Such insights can inform tailored training regimens focused on enhancing FFM, CMJ power, and hamstring strength, ultimately leading to improved athletic performance and reduced injury risks (Lee et al., 2024).

To enhance the performance and reduce the injury risk of female basketball athletes, it is essential to conduct comprehensive assessments of FFM, CMJ power, and maximum hamstring force. Implementing regular testing and monitoring of these variables can help in developing personalized training programs that address individual needs and weaknesses (Chen et al., 2013). Additionally, improving access to high-quality training facilities and coaching for female athletes can bridge the gap between current participation levels and the desired physical attributes for basketball. By leveraging scientific insights and tailored training strategies, the development and success of female basketball players can be significantly enhanced (Cabarkapa et al., 2023).

In competitive sports, particularly basketball, the physical attributes of athletes play a crucial role in performance outcomes. Basketball requires a unique blend of skills, including agility, speed, strength, and power, each of which contributes to an athlete's ability to perform essential movements such as jumping, sprinting, and rapidly changing direction (Akkoc et al., 2018). Understanding the intricate relationship between body composition, muscle strength, and explosive power is essential for optimizing training and injury prevention strategies tailored to the specific demands of basketball (Cirillo et al., 2023). This study aims to explore the correlation between fat-free mass (FFM), countermovement jump (CMJ) power, and maximum hamstring force in female basketball athletes, providing insights that could enhance performance and reduce injury risk.

Fat-free mass (FFM), which includes muscle mass, bone mass, and water content, is a critical determinant of athletic performance. Higher FFM is associated with greater muscle strength and power, which are vital for the explosive movements required in basketball, such as jumping, sprinting, and quick directional changes (Aikawa et al., 2020). Research has shown that athletes with higher muscle mass exhibit superior performance in strength and power-related tasks. FFM not only contributes to physical performance but also plays a significant role in metabolic health. Higher levels of FFM can increase the resting metabolic rate, which aids in maintaining optimal body composition and energy levels necessary for high-intensity sports (Torgutalp et al., 2022). The enhancement of FFM through resistance training and adequate protein intake is a well-documented approach in sports science aimed at improving athletic capabilities and reducing fat mass. This dual benefit makes FFM a key focus in the training regimens of basketball athletes (Zouita et al., 2023).

The countermovement jump (CMJ) is a widely used measure of lower body explosive power. It reflects an athlete's ability to generate force rapidly, which is crucial for jumping and sprinting actions in basketball. CMJ performance has been positively correlated with athletic success in various sports, highlighting its importance as an indicator of explosive power (Andreyo et al., 2024). Studies have shown that higher CMJ power is associated with improved performance in sprinting and jumping tasks. CMJ power is not only an indicator of explosive strength but also provides insights into the neuromuscular function of an athlete (Mocanu, 2023). The ability to produce a high power output during a CMJ requires optimal coordination between the nervous and muscular systems. This coordination is essential for executing rapid and forceful movements, which are common in basketball. Therefore, CMJ power serves as a comprehensive measure of an athlete's explosive capabilities and overall conditioning (AlSamhori et al., 2023).

Hamstring strength is essential for both performance and injury prevention in basketball. Strong hamstrings contribute to better sprinting speed, jumping ability, and overall lower body stability (Özkan et al., 2024). Moreover, adequate hamstring strength can reduce the risk of injuries, particularly hamstring strains, which are common in sports that involve high-speed running and sudden changes in direction. The hamstrings play a crucial role in deceleration, a frequent action in basketball when athletes must quickly stop or change direction (Jiang et al., 2023). Given the high incidence of hamstring injuries in basketball, understanding the factors that influence hamstring strength is crucial for developing effective conditioning programs. Hamstring injuries can have a significant impact on an athlete's career, often leading to prolonged periods of inactivity and rehabilitation. Therefore, identifying the relationship between hamstring strength and other physical attributes such as FFM and CMJ power can help in designing targeted interventions to enhance performance and reduce injury risk (Palma-Muñoz et al., 2021).

Female athletes often exhibit different muscle distribution and strength characteristics compared to their male counterparts. These differences can influence how body composition and power translate into athletic performance. Exploring these factors in female athletes can provide valuable insights for coaches and trainers who aim to optimize training programs specifically for women (Torgutalp et al., 2022). This study aims to fill this gap by exploring the correlation between FFM, CMJ power, and maximum hamstring force in female basketball athletes. Identifying these relationships is essential for developing targeted training interventions that enhance performance and reduce the risk of injury. By understanding how FFM and power contribute to hamstring strength, coaches and trainers can design more effective conditioning programs that address the specific needs of female basketball players (Nikolaidis et al., 2015).

This study aims to fill this gap by exploring the correlation between FFM, CMJ power, and maximum hamstring force in female basketball athletes. Identifying these relationships is essential for developing targeted training interventions that enhance performance and reduce the risk of injury. By understanding how FFM and power contribute to hamstring strength, coaches and trainers can design more effective conditioning programs that address the specific needs of female basketball players.

Materials and Methods

Study Participants

This cross-sectional observational study involved 45 female basketball athletes aged 16.5 ± 1.1 years. The mean body weight of the participants was 57.7 ± 9.4 kg, their mean height

was 163.8 ± 7.0 cm, and their mean body mass index (BMI) was 21.4 ± 2.6. These athletes were selected from four teams that had reached the semifinal phase of a competitive tournament.

Study Organization

Body Composition Measurement: Body composition, including fat-free mass (FFM), was measured using bioelectrical impedance analysis (BIA). The purpose of using BIA was to accurately determine the athletes' FFM, which is essential for understanding their physical makeup.

Physical Performance Assessment: Countermovement Jump (CMJ) Power, CMJ power was measured using a force plate to capture jump height and calculate power output. This assessment aimed to evaluate the explosive power of the athletes. Maximum Hamstring Force, this was evaluated using an isokinetic dynamometer, which provided detailed measurements of hamstring muscle strength. This method was used to assess the maximum force generation capacity of the hamstring muscles.

Research Procedures and Algorithm: Selection of participants from the semifinal teams, measurement of body composition using BIA. Assessment of CMJ power using a force plate. Evaluation of maximum hamstring force using an isokinetic dynamometer.

Statistical Analysis

Normality Test: The Anderson-Darling test was used to test the normality of the data. This test was chosen to determine whether the data followed a normal distribution, which is a prerequisite for many statistical analyses.

Correlation Analysis: Since the data were not normally distributed, Spearman's correlation coefficient was employed to analyze the relationships between FFM, CMJ power, and maximum hamstring force. Spearman's correlation is suitable for non-normally distributed data as it assesses the strength and direction of the association between two ranked variables.

Software and Data Presentation: All data analyses were conducted using MINITAB version 21 software. Scatter plots were used to visually present the data and illustrate the correlations between the measured variables.

Results

The data analysis identified significant positive correlations between fat-free mass (FFM) and maximum hamstring force for both the right leg ($r = 0.585$, $p < 0.001$) and the left leg ($r = 0.522$, $p < 0.001$). This indicates that individuals with higher FFM tend to exert greater maximum force in their hamstrings. Furthermore, countermovement jump (CMJ) power showed significant positive correlations with maximum hamstring force for the right leg ($r = 0.467$, $p = 0.001$) and the left leg ($r = 0.434$, $p = 0.003$), suggesting that greater leg power is associated with stronger hamstrings. Lastly, a strong positive correlation was observed between CMJ power and jump height ($r = 0.604$, $p < 0.001$), indicating that higher power output during a jump is associated with increased jump height.

The data above shows that there is a correlation between fat-free mass (FFM) and maximum hamstring muscle strength with a correlation value of 0.52 and a p-value < 0.001.

The data above shows that there is a correlation between countermovement jump (CMJ) and maximum left hamstring muscle strength with a correlation value of 0.43 and a p-value < 0.003.

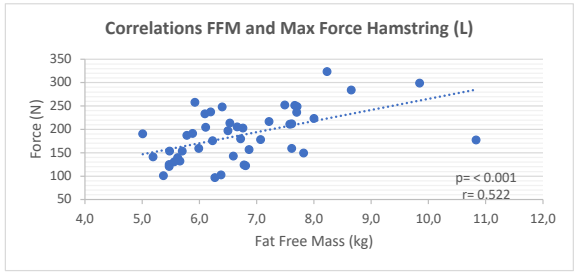

Fig. 1. Correlations FFM and Max Force Hamstring (L)

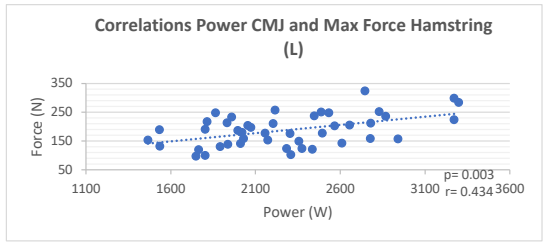

Fig. 2. Correlations Power CMJ and Max Force Hamstring (L)

The data above shows that there is a correlation between countermovement jump (CMJ) and maximum right hamstring muscle strength with a correlation value of 0.46 and a p-value < 0.001.

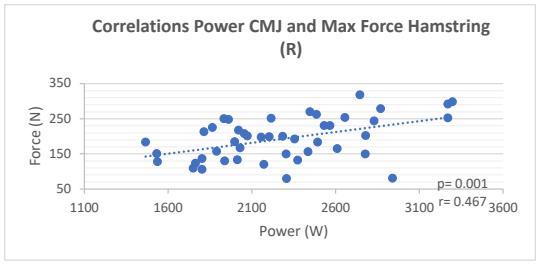

Fig. 3. Correlations Power CMJ and Max Force Hamstring (R)

The data above shows that there is a correlation between countermovement jump (CMJ) power and jump height ability with a correlation value of 0.6 and a p-value < 0.001.

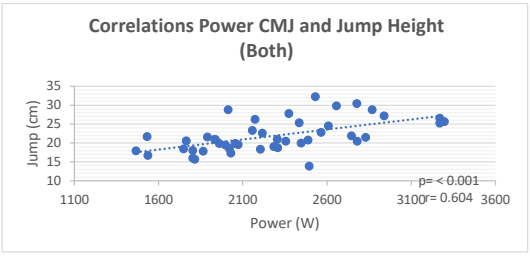

Fig. 4. Correlations Power CMJ and Jump Height (Both)

Discussion

The findings of this study underscore the importance of fat-free mass (FFM) and power in enhancing hamstring strength and explosive performance among female basketball athletes. The significant correlation between

FFM and maximum hamstring force highlights the role of muscle mass in generating force. This is consistent with previous research demonstrating that greater muscle mass contributes to higher force production capabilities (Jiang et al., 2023). FFM, which includes muscle mass, bone mass, and other non-fat tissues, is critical in force generation because muscles are the primary drivers of movement and force production (Campos et al., 2023).

The significant correlations between countermovement jump (CMJ) power and maximum hamstring force for both legs further emphasize the link between explosive power and muscle strength. CMJ power, a measure of an individual's ability to generate force quickly, is crucial for activities requiring rapid movements and high force output (Bell et al., 2014). This measure is particularly important in sports like basketball, where athletes frequently need to jump, sprint, and change directions quickly. The positive correlations suggest that individuals with greater power output also possess stronger hamstrings, which can be beneficial for athletic performance, particularly in sports requiring explosive lower body movements (Brumitt et al., 2013). This supports the notion that training to improve power can have direct benefits on strength, contributing to better performance in dynamic sports scenarios (Annino et al., 2017).

Moreover, the strong correlation between CMJ power and jump height illustrates the impact of power on vertical jump performance. Higher power output enables individuals to achieve greater jump heights, a key performance indicator in various sports (Chen et al., 2013). This relationship highlights the importance of power training for athletes aiming to improve their jump performance. Jump height is not only crucial for basketball but also for other sports like volleyball, soccer, and track and field, where explosive lower body movements are essential for optimal performance (Cuthbert et al., 2021). Effective power training can include plyometric exercises that focus on explosive movements, thereby improving the neuromuscular adaptations necessary for enhanced jump performance (Heishman et al., 2020).

These results have practical implications for training programs, emphasizing the need for strength and conditioning protocols that enhance FFM and power to improve athletic performance and reduce injury risk. Training programs that focus on increasing muscle mass and enhancing power output can lead to stronger hamstrings and improved jump performance, which are critical for basketball athletes (Palma-Muñoz et al., 2021). Strength and conditioning protocols should incorporate exercises targeting muscle hypertrophy and explosive power to maximize performance gains. For instance, plyometric exercises such as box jumps, squat jumps, and depth jumps can significantly enhance explosive power. Resistance training, particularly focusing on the lower body with exercises like squats, deadlifts, and leg presses, can increase muscle mass and strength, thereby improving overall athletic performance (Nikolaidis et al., 2015). Additionally, incorporating eccentric training, which emphasizes the lengthening phase of muscle contraction, can be beneficial for increasing muscle strength and reducing injury risk.

Future research should investigate longitudinal changes in these parameters and their impact on performance and injury prevention in a broader athletic population. Long-term studies could provide deeper insights into how sustained improvements in FFM and power influence overall athletic performance and reduce the risk of hamstring injuries, which are common in sports (McCaskie et al., 2023) requiring explosive movements. Understanding the long-term effects of training interventions can help in designing more effective strength and conditioning programs tailored to the specific needs of athletes, thereby enhancing performance and minimizing injury risks over the course of an athlete's career (AlSamhori et al., 2023). Such research could also explore the optimal training volumes and intensities needed to maximize gains in muscle mass and power while minimizing the risk of overtraining and injury (Gerodimos et al., 2023).

Conclusions

This study highlights the critical role of fat-free mass (FFM) and power in enhancing hamstring strength and explosive performance among female basketball athletes. The significant positive correlations between FFM and maximum hamstring force indicate that greater muscle mass contributes to higher force production capabilities in the hamstrings. Similarly, the strong correlations between countermovement jump (CMJ) power and both maximum hamstring force and jump height underscore the importance of explosive power in muscle performance and overall athletic ability. These findings have practical implications for designing strength and conditioning programs tailored to female basketball athletes. Emphasizing protocols that enhance FFM and power can lead to stronger hamstrings, improved jump performance, and reduced injury risk. Specifically, incorporating exercises that target muscle hypertrophy and explosive power will be beneficial in maximizing athletic performance.

Future research should focus on longitudinal studies to explore how sustained improvements in FFM and power influence performance and injury prevention across a broader athletic population. Understanding these relationships over time will provide deeper insights into optimizing training interventions and enhancing the long-term health and performance of athletes. In summary, this research provides valuable insights into the biomechanical factors that influence performance in female basketball athletes. By targeting FFM and power in training programs, coaches and trainers can significantly improve their athletes' strength, explosive capabilities, and overall athletic performance, ultimately leading to better outcomes on the court and a reduced risk of injuries.

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Conflict of Interest

There are no conflict of interest.

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Визначення кореляції показників безжирової маси тіла, потужності та максимальної сили підколінного сухожилля у спортсменок-баскетболісток

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

Реферат. Стаття: 6 с., 4 рис., 24 джерела.

Історія питання. У змагальних видах спорту, зокрема в баскетболі, фізичні якості, як-от спритність, швидкість, сила та потужність, є визначальними чинниками для досягнення результативності.

Мета дослідження. Мета дослідження полягала у вивченні кореляції між показниками безжирової маси (БЖМ) тіла, потужності вертикального стрибка з контррухом (ВСК) та максимальної сили підколінного сухожилля у спортсменок-баскетболісток, що сприятиме підвищенню рівня результативності та зниженню ризику травмування.

Матеріали та методи. У цьому обсерваційному поперечному дослідженні вивчався взаємозв'язок між показниками безжирової маси (БЖМ) тіла, потужності та максимальної сили підколінного сухожилля у 45 спортсменок-баскетболісток. З метою проведення дослідження використовували критерій Андерсона-Дарлінга для оцінки нормальності розподілу величин та рангову кореляцію Спірмена для ненормально розподілених даних.

Результати. Встановлено значні кореляційні зв'язки між показниками безжирової маси тіла і максимальної сили підколінного сухожилля правої ($r = 0,585$, $p < 0,001$) і лівої ноги ($r = 0,522$, $p < 0,001$), а також між потужністю вертикального стрибка з контррухом і максимальною силою підколінного сухожилля для обох ніг (права: $r = 0,467$, $p = 0,001$; ліва: $r = 0,434$, $p = 0,003$). Крім того, показник потужності суттєво корелював з висотою стрибка ($r = 0,604$, $p < 0,001$).

Висновки. Отримані дані свідчать про те, що показники безжирової маси тіла і потужності є вирішальними чинниками, що визначають силу підколінного сухожилля та вибухову продуктивність у спортсменок-баскетболісток.

Ключові слова: безжирова маса тіла, сила підколінного сухожилля, потужність, кореляція, спортсменки-баскетболістки.

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Evaluating Key Biomotor Abilities: A Comparison between National and International Elite Tennis Players

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Abstract

Background. Biomotor ability is essential for elite tennis players, as it significantly contributes to increased efficiency, responsiveness and overall performance on the court.

Objectives. This study aimed to assess and measure the biomotor abilities of elite tennis players, examining both national and international levels, and focusing on their physical and motor performance.

Materials and methods. The research involved a cross-sectional study of a total of 28 tennis players; among them, 15 were national players, and the remaining 13 were international players who served as subjects. The study focused on assessing eight key biomotor abilities: arm-shoulder strength and endurance, static muscular endurance, grip strength, power, speed, agility, and flexibility. Each test was conducted using appropriate equipment and standardized procedures, ensuring accurate score recording for analysis. The data was gathered at Super Shots Tennis Academy and Punjabi Bagh Club in Delhi, India. The statistical analysis involved calculating descriptive statistics (mean and standard deviation) and conducting an independent t-test to determine significance. The analysis was performed using SPSS Version 25, with a significance level of 0.05.

Results. The independent t-test comparing the biomotor abilities of international and national tennis players showed no significant differences in pull-ups, push-ups, speed, agility, or flexibility ($p > 0.05$). However, significant differences were found in wall squat hang, vertical jump, and hand grip strength ($p < 0.01$), with international players demonstrating superior performance.

Conclusions. In conclusion, the study reveals notable differences in certain biomotor abilities between international and national players, especially in static muscular endurance, explosive leg power, and hand grip strength. The findings suggest that national tennis players implementing targeted strength and power exercises, along with specialized endurance training, may exhibit enhanced overall biomotor abilities and improved on-court performance.

Keywords: biomotor abilities, strength and endurance, elite tennis player, motor performance.

Introduction

In the competitive world of tennis, an athlete's success depends not only on technical skill and strategy but also on key biomotor abilities. Tennis has evolved into a highly dynamic and explosive sport, characterized by its increasing physical demands and the speed of strokes and serves (Kovacs, 2007; Fernandez-Fernandez et al., 2009). This evolution has led to a significant shift in the focus of physical fitness training, which now aims to enhance physiological potential and develop biomotor skills essential for peak performance on the court (Radu, 2023). The intricate interplay of various biomotor qualities, particularly those related to strength is crucial for optimal performance in tennis, influencing critical aspects such as footwork and explosive strokes (Genevois, 2019; Dobos et al., 2021; Lambrich & Muehlbauer, 2022).

Central to understanding athletic performance in any sport is the concept of biomotor abilities—physical attributes that enable athletes to execute movements effectively. These abilities encompass strength, speed,

endurance, agility, flexibility, and coordination, each playing a pivotal role depending on the sport (Bompa & Haff, 2009). In tennis, strength and speed are particularly important, while endurance, agility, and coordination are equally critical for sustained high-level performance (Zatsiorsky & Kraemer, 2006). The assessment of these abilities is essential for evaluating an athlete's physical fitness, identifying areas for improvement, and determining effectiveness in sports competition (Baj-Korpak et al., 2022). Athletes' performance and well-being are heavily shaped by their physical fitness, with motor fitness playing a crucial role in the development of game-specific strategies and tactics (Reza et al., 2024).

Tennis, as a globally cherished sport, integrates skill, strategy, and athleticism, appealing to players and enthusiasts of all ages and abilities. Achieving excellence in tennis requires rigorous training regimens that include comprehensive assessments of both general and tennis-specific motor skills (Alexandru & Lorand, 2015; Reid et al., 2013). The growing field of sports science has become a crucial resource, offering evidence-based strategies to optimize athlete performance and minimize injury risks (Dewanti et al., 2019; Kovacs, 2007). Within this context, biomotor abilities such as strength, agility, endurance, and coordination are particularly significant (Junaidi, 2018; Fernandez-Fernandez et al., 2014). Understanding how these abilities influence tennis performance is crucial for enhancing player potential and guiding effective training methodologies (Yapıcı et al., 2018; Roetert & Ellenbecker, 2007). A comprehensive literature review revealed a significant relationship between physical motor abilities—such as muscle strength, endurance, speed, agility, and balance—and the enhancement of tennis performance skills (Nugroho et al., 2024).

One key aspect of tennis-specific training is the emphasis on early strength development, which plays a vital role in shaping musculoskeletal health. This holistic approach underscores the importance of balancing joint flexibility and muscular strength, especially in a sport that involves repetitive, high-intensity movements (Tsao et al., 2022; Cools et al., 2014; Ellenbecker & Roetert, 2003). A well-rounded fitness and flexibility training program enhances muscle strength, flexibility, and coordination, which not only lowers the risk of injury during training or competition but also increases range of motion (Rebecca, 2020; Rahman & Islam, 2020). For instance, the shoulder's range of motion is a critical factor in both performance and injury prevention in tennis (Chang & Qiu, 2022; Kibler & Safran, 2005). Additionally, to enhance hamstring strength and prevent injury, the hamstring curl is among the most effective exercises for increasing hamstring flexibility (Islam et al., 2024). Consequently, in-depth research into tennis-specific biomotor abilities aims to uncover the intricate relationship between physical fitness and on-court proficiency, providing valuable insights for tailored training interventions (Yapıcı et al., 2018; Reid et al., 2010).

Despite extensive research on general biomotor attributes like strength, agility, and endurance, there is a notable gap in assessing and comparing these abilities between national and international tennis players. The specific differences between players at varying competitive levels remain underexplored. This study aims to evaluate and compare the key biomotor abilities of national and international tennis players, identifying areas where national players may lag or excel. The findings will offer insights for targeted training interventions, ultimately enhancing player development and elevating tennis standards through evidence-based strategies.

Material and Methods

Subjects

Twenty-eight (n = 28) elite tennis players who have competed professionally were selected as subjects for the study. Among them, 13 were international players, and the remaining 15 were national players. Data collection was carried out at two selected sports academies or clubs in Delhi, India: R. K. Khanna Tennis Stadium and Super Shots Tennis Academy, Punjabi Bagh Club. The following Table 1 indicates (Mean ± SD) that the international and national players are relatively close in terms of mean values across all variables, with no statistically significant differences.

Variables and Criterion Measures

The study selected the following eight essential biomotor variables for assessment: strength, strength endurance, grip strength, power, speed, agility, and flexibility. Each test was conducted with proper equipment and standardized

Table 1. Characteristics of the subjects

Variables	Groups	n	Mean	Std. Deviation	Sig.
Age (yr)	International	13	20.85	3.31	0.25
	National	15	19.23	3.92	
Height (cm)	International	13	172.50	14.88	0.55
	National	15	169.46	11.12	
Weight (kg)	International	13	73.54	6.65	0.01
	National	15	66.40	7.35	
Body mass index (kg/m^2)	International	13	25.15	4.42	0.29
	National	15	23.40	4.06	
Training experience (yr)	International	13	10.38	2.60	0.16
	National	15	8.73	3.43	

Table 2. Variables and criterion measures

Variables	Test items	Unit of measure
Arm Strength	Pull up	Number (n)
Arm Strength and Endurance	Push up	Number (n)
Static Muscular Endurance	Wall Squat Hang	Second (s)
Leg Power	Vertical Jump	Centimeter (cm)
Hand Grip Strength	Hand Grip Dynamometer	Kilogram (kg)
Speed	20 m Sprint	Second (s)
Agility	T-Drill	Second (s)
Flexibility	Sit and Reach	Centimeter (cm)

procedures, with scores accurately recorded for analysis. This approach aimed to ensure a systematic and scientific assessment of biomotor abilities in elite tennis players.

Test Procedure

The upper body strength endurance test evaluates the endurance of the triceps, pectoral, and deltoid muscles through push-ups. Players perform as many push-ups as possible in one minute, maintaining proper form, with the score being the total number of correct push-ups (Hashim et al., 2018; Adams et al., 2022). In the pull-up test, participants begin with arms fully extended and shoulders flexed for 2 seconds. A valid rep requires the upper jawline to pass above the bar, returning to the starting position without swinging or kipping (Bartolini, 2022; Coyne et al., 2015). The wall squat test measures quadriceps endurance. Players slide into a 90° sitting position against a wall, lifting one foot 5 cm off the ground and holding it as long as possible. The score is the time each foot remains elevated (Mackenzie, 2005; Fukuda, 2019). Grip strength is tested using a dynamometer. Players squeeze it as tightly as possible while moving their arm through a 90° arc, with the best score out of three attempts recorded for each hand (Lupton-Smith et al., 2022; Rahman & Sharma, 2023). The agility T-test assesses a player's ability to change direction quickly through a T-shaped course, recording the best time out of three trials (Pauole et al., 2000; Miller et al., 2006; Sassi et al., 2009). The sit-and-reach test measures lower back and hamstring flexibility. Players reach forward from a seated position, with the distance reached beyond the toes recorded as the best of three trials (Wells & Dillon, 1952; Holt et al., 1999; Baltaci et al., 2003). The vertical jump test measures leg power by having players jump and mark the highest point they reach on a wall (Whitmer et al., 2015; Klavora, 2000). Finally, the 20-meter sprint test measures speed and acceleration, with the best time out of three attempts recorded (Liu et al., 1992; Alikhajeh et al., 2012). The researchers and their assistants conducted all tests, ensuring both consistency and accuracy throughout the study.

Statistical Analysis

The collected data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, such as the mean and standard deviation (SD), were used, and inferential analysis included conducting an independent sample t-test to assess significance levels. The Shapiro-Wilk test confirmed normal distribution, and Levene's test equality of variances. The study utilized SPSS Version 25 for analysis, with a significance threshold set at 0.05.

Results

The following Table 3 presents the descriptive statistics (mean and SD) of biomotor abilities, while Figure 1 shows that, on average, international tennis players have higher mean values compared to national tennis players.

Table 4 presents the results of independent sample t-tests comparing the biomotor abilities of international and national tennis players. For the pull-up, push-up, speed,

Table 3. Descriptive statistics of bio-motor abilities

Variables	Groups	n	Mean	Std. Deviation	Std. Error Mean
Pull up	International	13	6.69	4.25	1.18
	National	15	5.67	4.08	1.05
Push up	International	13	26.23	8.06	2.24
	National	15	23.67	11.15	2.88
Wall Squat Hang	International	13	44.23	11.38	3.16
	National	15	14.67	7.48	1.93
Vertical Jump	International	13	19.30	2.42	0.67
	National	15	16.08	3.73	0.96
Hand Grip Strength	International	13	31.38	6.42	1.78
	National	15	15.44	5.25	1.35
Speed	International	13	3.45	0.35	0.10
	National	15	3.62	0.56	0.15
Agility	International	13	11.48	0.58	0.16
	National	15	12.16	1.41	0.36
Flexibility	International	13	6.18	2.35	0.65
	National	15	4.65	2.49	0.64

Table 4. Independent sample t-test of biomotor abilities

Items	Groups	Mean difference	Std. error difference	t	df	Sig. (2-tailed)
Pull up	International National	1.03	1.58	0.65	25	0.52
Push up	International National	2.56	3.64	0.70	25	0.49
Wall Squat Hang	International National	29.56	3.70	7.99	20	0.00*
Vertical Jump	International National	3.22	1.18	2.74	24	0.01*
Hand Grip Strength	International National	15.94	2.24	7.13	23	0.00*
Speed	International National	0.67	0.40	0.98	24	0.34
Agility	International National	0.67	0.40	1.70	19	0.11
Flexibility	International National	1.53	0.92	1.67	26	0.11

*. Significant at 0.05 level

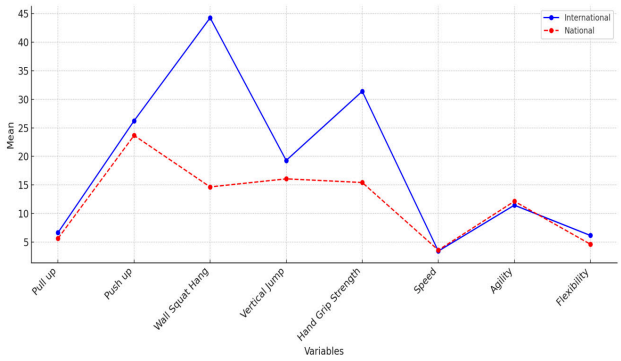

Fig. 1. Comparison of mean biomotor abilities

agility, and flexibility tests, no significant differences were found between groups: $t_{(25)} = 0.65$, $p = 0.52$; $t_{(25)} = 0.70$, $p = 0.49$; $t_{(24)} = 0.98$, $p = 0.34$; $t_{(19)} = 1.70$, $p = 0.11$; and $t_{(26)} = 1.67$, $p = 0.11$, respectively. However, significant differences were observed in the wall squat hang, $t_{(20)} = 7.99$, $p = 0.00$; vertical jump, $t_{(24)} = 2.74$, $p = 0.01$; and hand grip strength, $t_{(23)} = 7.13$, $p = 0.00$, indicating superior performance by the international players. The results indicate significant differences in specific biomotor abilities between international and national players, particularly in wall squat hang, vertical jump, and hand grip strength, at a significance level of 0.05.

Discussion

In the present study, as indicated in Table 4, significant differences were observed in hand grip strength, wall squat hang, and vertical jump. However, no significant differences were found in other strength variables, speed, agility, and flexibility. This finding is consistent with existing research, which presents a mixed view regarding differences in fitness abilities across various sports. For instance, research highlights that elite international male tennis players tend to exhibit superior leg power compared to their national counterparts. National level male tennis players average a vertical jump height of approximately 54 cm, while elite players typically achieve higher jump heights. This demonstrates enhanced explosive strength and power in their lower limbs (Farrow, 2013). In a study comparing international and national female tennis players, significant differences in functional asymmetries, particularly in lower extremity tests, were found. Nationally ranked players displayed greater asymmetry, whereas international players exhibited better symmetry and balance in their lower body strength. This is crucial for optimal performance in the dynamic and reactive environment of tennis (Chapelle et al., 2022). These findings align with previous studies, such as those by Kovacs (2007) and Fernandez-Fernandez et al. (2009), which emphasize the increasing physical demands of tennis, particularly the need for enhanced strength and explosiveness.

Additionally, a study by Ulbricht et al. (2016) compared young tennis players at different performance levels (regional vs. national teams), revealing significant differences in grip strength and 20-meter sprint times. Similarly, research on tennis players in the U12, U14, and U16 age groups found statistically significant differences in motor skills, particularly in tests like the 20-meter shuttle run, countermovement jump, and squat jump. These abilities tend to improve progressively with age, reflecting the increasing competitive demands at each performance stage (Barbaros et al., 2023). Moreover, Tamara et al. (2013) highlighted differences in motor abilities among Serbian national female tennis players in various age categories. Players aged up to 16 excelled in power and speed tests, while those up to 12 performed best in coordination-related tasks, influenced by their growth and training levels.

Training interventions like plyometric exercises can improve leg power and vertical jump performance (Thomas et al., 2009; Singh et al., 2024), while resistance training enhances grip strength (Thomas et al., 2008). Endurance exercises, such as wall squat hangs, effectively build both

upper and lower body strength and improve muscular endurance (Goldberg et al., 1994; Cho, 2013). Developing these biomotor skills not only boosts performance but also reduces injury risks from inadequate strength or endurance (Tsao et al., 2022; Ellenbecker & Roetert, 2003). Additionally, exercises like foot taps, jumping squats, lunges, and chin-ups significantly enhance agility, strength, and sport-specific skills (Fenta & Mola, 2023).

In summary, these studies highlight the critical role of physical conditioning in elite tennis, emphasizing how strength, endurance, power, speed, agility, and coordination progressively develop and distinguish players across different performance levels

Conclusions

In conclusion, the study found that international tennis players outperformed national players in static muscular endurance, explosive leg power, and hand grip strength. No significant differences were observed in pull-ups, push-ups, speed, agility, or flexibility. Targeted training in these key areas can help national players improve their biomotor abilities and overall performance, consequently enabling them to become elite international tennis players. Further research is needed to determine how these variables relate to performance success in elite tennis.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Оцінка ключових показників біомоторних здібностей: Порівняльний аналіз між елітними тенісистами національного та міжнародного рівнів

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

Реферат. Стаття: 8 с., 4 табл., 1 рис., 56 джерел.

Історія питання. Біомоторна здібність має важливе значення для тенісистів високої кваліфікації, оскільки зазначений чинник суттєво сприяє підвищенню ефективності, швидкості реакції та загальній результативності на корті.

Мета дослідження. Мета цього дослідження полягала в оцінці та вимірюванні показників біомоторних здібностей елітних тенісистів як на національному, так і на міжнародному рівнях, з акцентом на фізичну та рухову результативність гравців.

Матеріали та методи. Представлена наукова праця передбачала проведення поперечного дослідження за участю 28 тенісистів, серед яких 15 були гравцями національного рівня, а решта 13 — міжнародними гравцями, які виступали в якості випробовуваних осіб. Дослідження було зосереджено на оцінці восьми ключових показників біомоторних здібностей: сили та витривалості рук і плечей, статичної м'язової витривалості, сили хвату, потужності, швидкості, спритності та гнучкості. Кожен тест проводився з використанням відповідного обладнання та стандартизованих процедур, забезпечуючи точну фіксацію результатів з метою подальшого аналізу. Збирання даних проводилося в тенісній академії "Super Shots Tennis Academy" та клубі "Punjabi Bagh" у місті Делі, Індія. Статистичний аналіз включав розрахунок описової статистики (середнє значення та стандартне відхилення) та проведення методики застосування t-критерію для незалежних вибірок з метою визначення значущості. Аналіз проводився за допомогою програмного забезпечення SPSS версії 25 з рівнем значущості 0,05.

Результати. Т-критерій для незалежних вибірок, за яким порівнювали біомоторні здібності тенісистів міжнародного та національного рівнів, не виявив достовірних відмінностей у наступних показниках: підтягування, віджимання,

швидкість, спритність та гнучкість ($p > 0,05$). Однак спостерігалися значні відмінності у виконанні присідань з опорою на стіну, вертикальному стрибку та силі кистьового хвату ($p < 0,01$), де міжнародні гравці продемонстрували кращу результативність.

Висновки. Отже, проведене дослідження виявило помітні відмінності у певних біомоторних здібностях між гравцями міжнародного та національного рівнів, особливо у показниках статичної м'язової витривалості, вибухової сили ніг та сили кистьового хвату. Отримані дані свідчать про те, що тенісисти національного рівня, які виконують цілеспрямовані силові вправи в поєднанні зі спеціалізованими тренуваннями на витривалість, можуть продемонструвати поліпшення загальних показників біомоторних здібностей, а також підвищення рівня результативності на корті.

Ключові слова: біомоторні здібності, сила і витривалість, елітний тенісист, рухова результативність.

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Physical Activity Monitoring Model to Measure the Appropriateness of Weekly Physical Activity for the World Health Organization's Physical Well-Being and Health Claims

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Abstract

Objectives. The study aimed to test an agile monitoring tool to correlate physical activity levels for the 2 target age groups of school education with energy consumption.

Materials and methods. The sample consisted of 42 students, divided into two age-based groups: between 5 and 8 years of 24 and between 13 and 16 years of 18. Both were administered the adapted International Physical Activity Questionnaire (IPAQ), comprising ten questions, the first of which distinguished active athletes from others participants. The remaining nine questions were divided into sections: "intense activities", "moderate activities", and "walking only". The data on the amount of physical activity undertaken in the past seven days were converted to energy expenditure through the evaluative unit of Metabolic Equivalent of Task (MET).

Results. For subjects between 5-8 years who were active in sports, the weekly average was 3355.2 METs, with 1577 for intense activities, 1617 for moderate activities, and 159.7 for walking. Among subjects in the 13-16 years age group who were active in sports, the weekly average was 3799.5 METs, with 3376 for intense activities, 577.6 for moderate activities, and 529.9 for walking. For the same age group who were not engaged in sports activity, the weekly average was 594.5 METs, with 20 for intense activities, 360 for moderate activities, and 214.5 for walking.

Conclusions. The findings show that it is possible to use the physical activity monitoring tool proposed in the study, with the measurement of METs.

Keywords: caloric consumption, metabolic equivalent of task, questionnaire.

Introduction

Daily caloric consumption is defined as a measure of the amount of energy an individual uses during daily activities (Taylor & Keys, 1950). It is considered a key element in the common understanding of physical activity levels (Shock, 1972). This is confirmed by the introduction of compulsory teaching of physical education by the teacher with a master's degree in exercise science to bring down the levels of overweight and obesity in the Italian population (Cole et al., 2000; D'Isanto, 2019; Raiola et al., 2018). This measure was reinforced with the strengthening of physical education and sports with the reinstatement of the Youth Games. In addition, the educational and social value of physical activity, as well as its psychophysical effects for proper health education and psychophysical well-being, has been included in the Italian Constitution (Gazzetta Ufficiale, 2022). The age variable is crucial in school education to better understand physical activity levels (Raiola, 2017). This is especially important during the first cycle of elementary school and the first cycle of secondary school (Raiola, 2020). During these periods, children and adolescents may develop habits

related to physical activity that will influence their daily lives. It is essential to gain knowledge about these levels during these stages of growth, as this can have a significant impact on their life habits and future health (Taylor et al., 2014). Numerous studies have amply demonstrated the importance of practicing physical activity (Chatzipanteli et al., 2015; Pethkar et al., 2010; Esposito, 2024) accompanied by the already expected evidence on the educational function of movement (Raiola, 2019). In fact, such studies show that physical activity produces positive effects on those who practice it on a physical level, having beneficial effects on the cardiovascular system, preventing hypertension, helping to control weight (Beunen et al., 1981). Understanding, even superficially, caloric consumption is not limited to static assessment, but requires continuous monitoring in the context of daily activities and, therefore, should be introduced into school education (Aliberti, 2023). A dynamic and timely assessment of energy consumption is essential to combat sedentariness and to initiate accurate identification analyses (Raiola, 2015; Raiola, 2014). The study of caloric expenditure is also crucial for developing personalized, evidence-based weight management strategies (Castro et al,2020; Fischer & Johnson, 1990). In scientific literature, no agile tools are found that allow monitoring of calorie expenditure because of congruous physical activity for the purpose of mental and physical well-being as indicated by the World Health Organization (WHO) and recently included in the Italian Constitution.

Purpose of the research – The main objective of this study is to test a new agile monitoring tool that is efficient and flexible to establish a correlation between physical activity levels and energy consumption. This tool will be applied to two target age groups in school education, thus enabling a detailed overview of children's and adolescents' physical activity habits.

Materials and Methods

Study Participants

Forty-two students participated in the study, divided into two groups according to their age group: between the ages of 5 and 8 composed of 24 units, corresponding to the early years of primary school education, and between the ages of 13 and 16 composed of 18 units, corresponding to the early years of secondary school education. The sample was selected randomly.

Study Organization

A questionnaire was developed, adapting a version of the International Physical Activity Questionnaire (IPAQ) for the purpose. The latter's main objective is to assess the type and frequency of physical activity performed during the last week of the subject under study. Due to the age of the sample, for both the 5-8 age group and the 13-16 age group, the responses are made by the parents of the study participants. It contains ten questions, the first being useful in creating a division between those who play sports and those who do not. The next four questions have been divided into two different sections. In the "intense activity" section. In the "intense activity" section, subjects were asked whether they had engaged in intense physical activity in the past seven days and for how many minutes. Intense activity is defined as that type of activity that involves high physical exertion that forces breathing at a much higher rate than normal. In the moderate activity section, subjects were asked whether they had engaged in moderate physical activity in the past seven days and for how many minutes Moderate physical activity is defined as that type of activity that involves moderate physical

Table 1. Questionnaire

Questions	Answers
Do you practice sports? (Practicing sports is defined as engaging in structured sports activity for at least 2 days a week of 1h 30min each)	-Yes -No
1A) In the past 7 days, on how many days did you engage in intense physical activities such as sports training, aerobic activities such as running or bicycling at high speed?	(Indicate the number of days, if the answer is zero go to question 2)
1B) How much time in total did you normally spend performing intense physical activities on any of these days:	(Indicate the number of minutes)
2A) For how many days in the past 7 days did you engage in moderate physical activities, such as playing in the park, riding a bicycle at a regular speed?	(Indicate the number of days. Do not consider walks)
2B) How much time in total did you normally spend doing moderate physical activities on any of these days?	(Indicate the number of days)
3A) In the last 7 days, how many days did you walk for at least 10 minutes? Consider any walking for a move from one place to another	(Indicate number of days per week, if zero go to question 4th)
3B) How long in total did you normally walk on any of these days?	(Indicate number of minutes)
3C) At what pace did you predominantly walk?	-Intense pace -Moderate pace -Slow pace, without any change in respiratory rate
4A) In the past 7 days, how much time in total did you spend sitting during a weekday?	(Mean time spent at school, at home on the couch, at the table) Give the number in hours.
4B) In the past 7 days, how much time in total did you spend sitting during a weekend day?	(Indicate the number of hours)

exertion and only partially forces breathing at a higher rate than normal. Once the type and amount of physical activity performed by the subjects surveyed had been analyzed, in the "walking" section we proceeded to investigate whether they had walked for at least 10 minutes in the past seven days, meaning it as moving from one place to another, and in the case of an affirmative answer they were asked how many minutes in a day they had walked. The last question was about the sustained pace in walking, slow, moderate or intense. The last section of the questionnaire, called "sitting activity," on the other hand, concerns the hours participants spent sitting on any of the weekdays, for example, hours spent at school and hours spent sitting on any of the weekend days. All this is shown in Table 1.

Once the questionnaire is administered, the results are analyzed using the International Physical Activity Questionnaire (IPAQ) interpretation table, which is used to understand whether a subject is:

- Active: performs an optimal amount of physical activity;
- Sufficiently active: performs sufficient physical activity to maintain physical well being;
- Inactive: does not engage in sufficient physical activity to maintain good health.

The table is based on the Metabolic Equivalent of Task (METs), useful values for quantifying the energy consumed during physical activity; one MET corresponds to 1 Kcal per kg body per hour. Through mathematical formulas physical activity energy consumption divided by resting energy consumption, the METs that each individual consumes during intense, moderate physical activity and in walking are calculated. The sum of these METs gives the total weekly energy consumption. If the total weekly METs is less than 700, the individual is found to be inactive; if it is between 700 and 2519 METs, the individual is considered sufficiently active; if it exceeds 2520 METs, the individual is classified as active or very active. If the total is less than 700 Met: INACTIVE. If the total is between 700 and 2519 Met: SUFFICIENTLY ACTIVE. If the total is more than 2520 Met: ACTIVE OR VERY ACTIVE. This is summarized in Table 2.

Table 2. METs (Metabolic Equivalent of Task) Table, interpretation of the questionnaire

METs (Metabolic Equivalent of Task) Table, interpretation of the questionnaire
Met intense activities = minutes * days * 8 Met
Met moderate activities = minutes * days * 8 Met
Met activity walk = minutes * days * 3 if moderate, *3.3 if intense, *2.5 if slow
Total Met = Met activities together + Mett activites moderate + Met walks =…

Statistical Analysis

Descriptive statistics was used in data analysis to examine mode, mean, median and standard deviation. It was verified that the data had an approximately normal distribution. Statistical processing was conducted using SPSS statistical software, ensuring accurate and detailed analysis of the results.

Results

From the analysis of the results, it was found that to the first question, that is, 'Do you practice sports?' 66.6 % of the respondents practice sports, 33.4 % do not as shown in Table 3. In terms of numbers out of 42 participants 28 subjects practice sports and the remaining 14 do not.

Table 3. Percentage sportsmen and non-sportsmen

Percentage sportsmen and non-sportsmen	Total sample	Age group 5-8 years	Age group 13-16
% Athletes	66.6	90	46
% Not athletes	33.4	10	54

In the "intense activities" section to the question regarding physical activity that was performed intensively in the subject's last 7 days, considering only the answer "0," the percentage of individuals who did not perform it stands at 18.8 %. When analyzing the total minutes that individuals spent performing intense physical activity, it is found that the average value is 110 minutes, in a range from 90 to 130 minutes, with only 4 individuals performing intense activity for less than this range, which is 75 minutes, and only two individuals performing activity for 180 minutes, exceeding the previously mentioned range. Going to analyze the "moderate activity" section, all participants say they have done moderate physical activity in the past 7 days, 14.3 % say they did it for only one day while only 9.5 % did it for 7 days. The average number of days on which moderate physical activity was done in the last 7 days is 3.5 days. Next, the total minutes devoted to moderate activity was analyzed. The peak number of minutes recorded for a single individual is 240. The average number of minutes spent in moderate physical activity is 77.4. In the "walking" section 32 individuals, or 76.2 % of respondents say they have walked for at least one day in the past 7 days. 25 % walked for 3 days, 12.5 % walked only one day, and 18.8 % walked every day. Respondents in 33.3 % indicated that they walked within a day for a total of 20 minutes, 13.3 % for 15 minutes. The highest figure corresponds to 75 minutes, time spent by 6.7 % i.e., two individuals. The average number of minutes spent walking is 26.6 minutes total. The last question in the "walking" section was analyzed by the pace at which individuals did their walking. 0 % voted intense pace, while 68.8 % indicated walking at a slow pace and 31.3 % at a moderate pace. The last data that was analyzed concerns the total time an individual spent sitting on a weekday in the last 7 days, the figures that appear most, indicated by 19 % respectively are 7 hours, 8 hours and 10 hours. The average time spent sitting is 6.8 hours per day. On a weekend day, 19 % of respondents reported sitting for a total of 4 hours and 6 hours, fashion data. The average number of hours individuals spent sitting on a weekend day is 5 hours. Analyzing the totality of the sample taken, the average METs consumed in intense activities is 1485.7 METs weekly, the average METs consumed in moderate activities is 950.8, while in walking on average 255.9 METs are consumed in a week. The average METs that are consumed in total is 2691.5 weekly. Considering only the class of those who practice sports in the 5-8 years age group, the average METs consumed in intense activities is 1577, METs consumed in

Table 4. Calculation of the average METs

Calculation of the average METs	Total sample	Age group 5-8 years who play sports	Age group 5-8 years who do not play sports	Age group13-16 years old playing sports	Age group 13-16 years who do not play sports
Mean METs att. Intense	1485.7	1577	0	3376	20
Mean METs moderate att.	950.8	1617	360	577.6	360
Mean METs walk	255.9	159.7	0	529.9	214.5
Mean METs total	2691.5	3355.2	360	3799.5	594.5

Table 5. Percentage of active and inactive subjects

Percentage of active and inactive subjects	Total sample	Practice sports	Not practice sports	Age group 5-8 years old	Age group 13-16 years old
%inactive	23.8	0	100	0	100
%Suff. active	19	50	50	50	50
%Super active	57.2	100	0	58.3	41.6

moderate activities is 1617, and the average METs consumed in walking, on the other hand, is 159.7. Finally, the average total METs that are consumed in a week is 3355.2. For the class of those who play sports in the 13-16 range, the average of METs consumed in intense activities is 3376. The average of METs consumed in moderate activities is 577.6, the average of METs consumed in walking 529.9. The average of total METs consumed in a week is 3799.5. In the 13/16 range, the average METs consumed by nonsports people in intense activities is 20, in moderate activities is 360. The average METs that are consumed in walking 214.5. Finally, the average total METs consumed over a week is 594.5. This can be seen in Table 4.

In the 42 subjects surveyed as a whole, 23.8 %, are found to be inactive; on the other hand, 19 % are found to be sufficiently active, while the remainder, 57.2 % are found to be very active. 100 % of those who are inactive do not play sports and are in the 13-16 age group. The percentage of those who are sufficiently active is divided 50 % between those who play sports and those who do not. The percentage of those who are found to be very active and play sports is 100 %. All this can be noticed in Table 5.

Table 6 shows the percentage increase in the consumption of METs that occurs in the 13-16 age group compared to the 5-8 age group, considering only those who participate in sports. Total METs, consumed in intense, moderate and walking activities, are considered. In intense activities the increase in METs is 114 %, in moderate activities -179.9 %, in walking 107 %, and finally in the total account of METs consumed in a week the increase is 13.2 %.

The total METs consumed in one week in the 13-16 age group by those who play sports is 3204.5 greater than those who do not play sports. In the analysis of METs consumed in intense activities, the difference stands at 3356 METs in favor of those who play sports. In moderate activities, on the other hand, those who play sports consume an average of 217.6 METS more than those who do not. Finally, in walking, the difference is 315.4 METs in favor of those who practice sports. This has been reported in Table 7.

Table 6. Percentage increase in the consumption of METs

Percentage increase in the consumption of METs	In the 13-16 athletes
Increment % METs att.intense	114
Increment % METs att.moderate	-179.9
Increment % METs walk	107
Increment % METs total	13.2

Table 7. Total METs consumed in a week

Total METs consumed in a week	
Mean difference METs consumed in intense att.	3356
Mean difference METs consumed in moderate attitudes	217.6
Mean difference METs consumed in walking	315.4
Mean difference METs consumed	3204.5

In the 13-16 age group, there is a 500 % increase in those who do not participate in sports compared to the 5-8 age group. Finally, the average hours individuals spend sitting on weekdays and holidays was analyzed. The analysis shows that on weekdays children in the 5-8 age group who play sports on average sit 7.1 hours compared to 8 hours for those who do not play sports, while on holidays those who play sports on average sit 3.6 hours; those who do not play sports 10 hours. In the 13-16 age group, those who play sports on weekdays sit an average of 7.2 hours, compared to 8.1 hours for those who do not play sports, while on holidays those who play sports on average sit 4.4 hours; those who do not play sports 7 hours. As demonstrated in Table 8.

Table 8. Mean hours sitting

Mean hours sitting	Age 5/8 Sport yes	Age 5/8 Sport no	Age 13/16 Sport yes	Age 13/16 Sport no
Mean hours sitting on weekdays	7.1	8	7.2	8.1
Mean hours sitting on holydays	3.6	10	4.4	7

Discussion

Two age groups were considered in the results section: individuals between 5 and 8 years old and individuals

between 13 and 16 years old. The data collected shows that about 60 % of individuals in these age groups practice sports regularly, a result in line with what was reported in the ISTAT surveys. This finding is also reflected in the sample surveyed, where 66.7 % of respondents say they play sports. The WHO guidelines recommend intense physical activity of at least 60 minutes a day for at least three days a week for these age groups, flanked by moderate activity on the other four days (D'Elia et al., 2019). However, only 33.3 % of respondents engage in intense activity according to these guidelines, although the total duration of physical activity exceeds the requirement set by the WHO for the entire sample. As for moderate activities, all participants report doing them, but the average number of days devoted to them is slightly lower than recommended by the WHO. The latter also emphasizes the health benefits of walking at a moderate pace, recommending at least 30 minutes a day on all days of the week. However, only a minority of respondents say they walk every day, with the average amount of time spent on walks not fully meeting WHO guidelines (D'Elia, 2020). An analysis of METs consumed in various activities shows that individuals who participate in sports tend to consume significantly more than those who do not, in all age groups considered. In particular, there is a significant increase in METs consumed in the 13-16 age group compared to the 5-8 age group, with the exception of moderate activities. In the 5-8 year age group, in intense activities, sports children consume 1577 METs weekly compared to 0 for those who do not participate in sports. The value 0 is also found in the METs consumed by those who do not participate in sports in the walk analysis. Sportsmen consume 159.7 METs per week by walking. In moderate activities, sportsmen consume 1617 METs, those who do not participate in sports 360. Comparing the total METs that are consumed by those who play sports and those who do not play sports will show that those who play sports consume 9.32 times the METs of those who do not play sports in a week. Even in the age group of 13- to 16-year-olds, the basic thesis would seem to be confirmed. In fact, on average in intense activities, those who practice sports consume 3376 METs weekly compared to 20 METs consumed by those who do not. The METs consumed in moderate activities also confirm this, 577.6 is the average METs that sportsmen consume weekly, only 360 on the other hand are consumed by those who do not practice sports. In walking, those who play sports consume 529.9 METs, while those who do not practice sort consume 214.5, less than half. In tallying the total METs consumed on average in a week, the trend is confirmed in that sportsmen in the age group 13-16 consume an average of 3799.5 METs compared to 594.5 for those who do not practice. The difference is as much as 3205 weekly METs. We now consider data regarding METs consumed only by those who participate in sports, comparing those consumed by subjects in the 5-8 range and subjects in the 13-16 range. In the tally of METs spent on average in the intense activities, in those in walking, and in the total calculation of the week, it will be possible to see a marked increase in METs consumed in the adolescent group compared to the preadolescent group. Only in moderate activities will the METs consumed decrease, from 1617 in the 5-8 range to 577.6 in the 13-16 range. Finally, there is an increase in time spent sitting on holidays compared to weekdays, with a more pronounced difference between those who play sports and those who do not, especially in the 5-8 age group.

Conclusion

The study investigated the importance of caloric consumption as a key indicator for assessing physical activity levels, focusing on two age groups in developmental age. It was found that a defined agile monitoring tool can be effective in assessing physical activity measured in METs. This is evident from the results that provided insight into whether a subject was inactive, sufficiently active, or very active. However, the sample size is a limitation that requires expansion. Nevertheless, the study indicates potential opportunities in the field of tracking and monitoring physical activity, thus contributing to the effectiveness of school education on mental and physical health and well-being.

Conflict of interest

The authors declare that there is no conflict of interest.

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Модель моніторингу фізичної активності в контексті вимірювання відповідності рівня щотижневої фізичної активності вимогам Всесвітньої організації охорони здоров'я щодо фізичного благополуччя та стану здоров'я

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

Реферат. Стаття: 7 с., 8 табл., 21 джерел.

Мета дослідження. Мета цього дослідження полягала в перевірці використання гнучкого інструменту моніторингу щодо кореляції рівнів фізичної активності для 2 цільових вікових груп шкільної освіти з енергоспоживанням.

Матеріали та методи. Вибірка складалася з 42 учнів, розділених на дві вікові групи: 24 особи віком від 5 до 8 років та 18 осіб віком від 13 до 16 років. Обом групам було запропоновано адаптований Міжнародний опитувальник фізичної активності ("International Physical Activity Questionnaire", IPAQ), що включав десять запитань, перше з яких давало змогу відрізнити активних спортсменів від інших учасників. Решта дев'ять запитань розподілялися за розділами: «інтенсивні навантаження», «помірні навантаження» та «виключно ходьба». Отримані дані щодо кількості фізичної активності, виконаної за останні сім днів, конвертувалися у витрати енергії за допомогою оціночної одиниці метаболічного еквіваленту навантаження (MET).

Результати. Для осіб віком 5-8 років, які активно займалися спортом, середньотижневий показник становив 3355.2 MET, з яких 1577 для інтенсивних навантажень, 1617 — помірні навантаження і 159.7 — ходьба. У віковій групі 13-16 років, які активно займалися спортом, середньотижневий показник складав 3799.5 MET, з яких 3376 для інтенсивних навантажень, 577.6 для помірних навантажень і 529.9 для ходьби. Для учасників аналогічної вікової групи, які не займалися спортом, середньотижневий показник становив 594.5 MET, з яких 20 — інтенсивні навантаження, 360 — помірні навантаження і 214.5 — ходьба.

Висновки. Результати дослідження показали можливість використання запропонованого в роботі інструменту моніторингу фізичної активності, що включало в себе вимірювання показників MET.

Ключові слова: споживання калорій, метаболічний еквівалент навантаження, опитувальник.

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Original Scientific Article

Self-Confidence and Cognitive Speed: Key Predictors of Topspin Accuracy in Competitive Table Tennis

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Abstract

Background. Table tennis players often use topspin shots in order to score. For many athletes, this stroke is crucial to winning, making it a favorite among players. It is more probable that accurate topspin strokes will make it harder for opponents to return the ball. As a result, players who can maintain topspin stroke accuracy over time are more likely to win matches.

Objectives. This study aimed to examine the association between self-confidence (SC) and cognitive processing speed (CPS) with topspin accuracy (TPA) in table tennis.

Materials and methods. This study used a correlation method with a quantitative approach. A total of 82 participants (aged: 20.0 ± 0.6 years) were involved in this study. Data on topspin accuracy was collected by administering a topspin accuracy test, followed by administering a self-confidence questionnaire and cognitive processing speed test. Pearson correlation and linear regression analysis were used to determine the association between the variables.

Results. The findings of this study show (1) a positive relationship between self-confidence and topspin accuracy ($r = 0.430$, $p < 0.05$); (2) a positive relationship between cognitive processing speed and topspin accuracy ($r = 0.374$, $p < 0.05$).

Conclusions. Topspin accuracy is influenced by cognitive processing speed and self-confidence. Therefore, in order to improve table tennis topspin performance, coaches should take these factors into account. The results of this study can have a significant impact on training programs, where mental skills training, such as boosting self-confidence and enhancing cognitive processing speed, should be integrated into technical and tactical training routines. This approach will allow athletes to not only refine their physical skills but also strengthen their psychological resilience, ultimately leading to better performance in competitive matches.

Keywords: intelligence capability, emotion state, cognitive response, stroke precision, accuracy in racket sport.

Introduction

It has long been known that table tennis is a sport that emphasizes quick reflexes, accuracy, and strategic gameplay (Huang et al., 2023). Table tennis stands out as a fast-paced sport demanding exceptional speed and precision. This dynamic requires athletes to swiftly process visual and spatial information, ensuring swift and accurate responses during gameplay. Understanding the nuanced interplay between physical agility and cognitive acuity in table tennis is essential for optimizing training methodologies and enhancing competitive performance (Zhang, 2022). Precision in executing targeted hitting techniques allows athletes to strategically position the ball in challenging

areas for their opponents, thereby optimizing scoring opportunities. In sports, precision serves as a fundamental determinant that significantly influences competitive results, highlighting its critical role in enhancing performance outcomes (Amaro et al., 2022; Özdalyan et al., 2022). In the increasingly competitive landscape of table tennis, the ability to achieve precise shot execution, notably in topspin shots, is recognized as pivotal for determining competitive outcomes. This underscores the significance of accuracy in technique as a decisive element in achieving success in high-level competition (Iordan et al., 2021). The topspin technique, which imparts forward rotation to the ball, enhances players' ability to control both the speed and trajectory of their shots, thereby presenting added challenges for opponents in returning these balls (Kidokoro et al., 2022). Accurate topspin execution plays a pivotal role in table tennis, allowing players to finely control the ball and dictate the pace of the game. The ability to consistently deliver precise topspin strokes frequently dictates match outcomes, especially in competitive settings (Firdaus & Mario, 2022). Moreover, athletes who demonstrate high accuracy in their performance are more likely to achieve victory compared to those with lower levels of accuracy (Karišik et al., 2018).

Self-confidence in sports has garnered significant attention from researchers due to its crucial role in athlete performance. A study in martial arts explain that female athletes demonstrated greater self-confidence than male athletes. Moreover, younger athletes exhibited higher levels of cognitive anxiety compared to adult athletes. These results highlight gender and age as notable factors influencing psychological traits in athletes (Contessoto et al., 2020). In addition, athletes who accumulate more playing experience and invest greater time in training tend to demonstrate heightened levels of self-confidence. This observation underscores the importance of extensive experience and dedicated training regimens in fostering athletes' belief in their abilities, thereby enhancing their overall performance readiness and competitive outcomes. These insights underscore the significance of structured training programs and sustained participation in competitive settings as key contributors to athletes' psychological preparedness and confidence levels (Neves et al., 2022). A descriptive study identified that male swimmers exhibit higher levels of self-confidence and lower levels of anxiety compared to their female counterparts. Moreover, varying levels of self-confidence and types of anxiety are observed across different competitive specialties and ranks of competitions. This study also highlights gender differences and the nuanced psychological dynamics influenced by competitive contexts within swimming disciplines (Silva et al., 2019; Peron & Elsner, 2020). Furthermore, Para-athletes who possess emotional stability, cognitive flexibility, mental endurance, self-confidence, effective stress management, and emotional control tend to achieve greater success in sports. These attributes play crucial roles in navigating the challenges of competitive environments and optimizing performance outcomes in para-sport disciplines (Ersöz & Esen, 2023). The study reveals a significant correlation between physical appearance and self-confidence. Therefore, it is recommended that women be encouraged to engage in sports activities, as this can enhance their physical strength and bolster their self-confidence. Promoting active participation in sports can be a vital strategy for improving women's overall well-being and self-assurance (Basaran, 2022).

Cognitive processing speed is pivotal in sports performance, particularly in conjunction with accuracy. Research indicates that extended cognitive exertion during physical activity can compromise decision-making by lengthening reaction times and increasing variability, albeit without impacting accuracy (Tsukamoto et al., 2022).

Furthermore, studies investigating the speed-accuracy trade-off in cognitive tasks indicate that distinct neurocognitive systems are engaged in processing speed and accuracy independently. Research shows varying neural activities in the supplementary motor area and prefrontal cortex, reflecting individual preferences and abilities toward either speed or accuracy (Perri et al., 2014). Moreover, technological advancements such as the COGNIFOOT system enable objective, real-time assessments of cognitive-motor performance in sports. This system has demonstrated age-related enhancements in passing accuracy, speed, and reaction times among young elite soccer players (Hicheur et al., 2017). A recent study demonstrates that cognitive processing speed profoundly influences accuracy in cognitive tasks throughout the lifespan. This correlation suggests potential implications for sports performance, prompting a need for further investigation in this area (Bonnechère, 2022). The cognitive processing efficiency theory posits that in team sports, elevated cognitive anxiety and mental exertion are associated with performance outcomes, particularly noticeable in highly trait-anxious players during critical game moments (Smith et al., 2010).

Previous studies investigating hitting accuracy in table tennis have highlighted the significant impact of kinematic variables such as shoulder angular velocity, wrist angle, and racket horizontal velocity on topspin forehand accuracy. These findings underscore the complex biomechanical factors influencing shot precision (Alkhawaldeh, 2022). The precision with which an athlete directs the ball to a specific target area is influenced by both the athlete's skill level and the skill level of the opponent (Le Mansec et al., 2016). Furthermore, speed and accuracy in performance are influenced by an individual's cognitive function, which can be impacted by both physical and mental fatigue (Mikicin, 2022; Le Mansec et al., 2018). A study from Niźnikowski et al. (2022) involving novice table tennis players, indicated that those who focused on targeting the ball during their shots showed significantly greater improvements in hitting accuracy compared to those instructed to focus on correcting their grip. Shot accuracy in table tennis varies depending on the type of stroke used, exhibiting distinct differences in shot characteristics among female players. This underscores the need for a nuanced approach to analyze and enhance performance outcomes tailored to different player demographics (Wang et al., 2022). High accuracy in ball placement and the speed-ball placement index underscores the importance of precise control over the landing position of the ball on the table for successful shots in table tennis. Interestingly, shot accuracy is not solely contingent upon ball speed, highlighting the significant roles played by factors such as timing, angle, and spin in determining shot effectiveness (Belli et al., 2019). Moreover, an experimental study aimed at enhancing topspin shot accuracy involved providing elastic bands as a treatment to 12 table tennis players. The results of this study demonstrated a significant

improvement in topspin accuracy compared to players who did not receive elastic band training, attributed to enhanced muscle coordination and physical control abilities (Nikolakakis et al., 2020). Consistent with the previous statement, the velocity of the wrist joint during ball impact directly influences both the speed and rotation of the ball (Zheng et al., 2021). Both mental and muscular fatigue contribute to a decrease in the quality of players' strokes during competition (Le Mansec et al., 2017).

While many studies have explored physical factors influencing athletic performance across sports, there is a significant gap in understanding correlation between self-confidence and cognitive processing speed with top spin stroke in table tennis. Topspin accuracy is crucial for precise ball control and game tempo regulation in table tennis. However, the psychological aspects such as self-confidence and cognitive processing speed impact for topspin accuracy remains unclear. This study aims to address this gap by investigating the association between self-confidence, cognitive processing speed and top spin stroke accuracy. By examining how these factors contribute to the precision and consistency of topspin strokes, the research seeks to inform more effective athlete training programs and advance knowledge in sports science literature.

Materials and Methods

Study Design and Participant

In this study, a quantitative correlational research design was utilized to investigate the relationship between upper relationship between self-confidence, cognitive processing speed and topspin accuracy and topspin accuracy in table tennis. The sample consisted of 82 students from the coaching department at the Faculty of Sports Science, Universitas Negeri Padang, Indonesia. These students were divided into two classes of Table Tennis II courses, with 55 males and 27 females, aged between 19 and 21 years. Participation in Table Tennis II required prior completion of the Table Tennis I course, ensuring that students had already mastered the proper topspin technique. Detailed characteristics of the participants are provided in Table 1.

Table 1. Descriptive characteristics for the total sample and separately for male and female participants. Values are mean ± standard deviation

Indicators	Total Sample (n = 82)	Female participants (n = 27)	Male participants (n = 55)
Age (years)	20.0 ± 0.6	20.0 ± 0.6	20.0 ± 0.5
Height (cm)**	159.4 ± 4.1	157.4 ± 4.5	160.4 ± 3.5
Body weight (kg)**	55.2 ± 4.4	52.1 ± 3.7	56.7 ± 3.9
BMI (kg/m^2)*	21.7 ± 1.8	21.1 ± 1.3	22.1 ± 1.9
Training experience (years)*	3.4 ± 1.2	2.9 ± 1.3	3.6 ± 1.1
Self-confidence (points)	97.6 ± 7.7	95.9 ± 7.6	98.5 ± 7.7
Cognitive processing speed (points)	31.9 ± 6.3	33.3 ± 5.7	31.2 ± 6.5
Topspin accuracy (points)	18.8 ± 3.4	18.8 ± 4.0	18.8 ± 3.1

** sig. sex difference, $p < 0.01$; * sig. sex difference, $p < 0.05$

Instrument

Self-confidence

The questionnaire used in this study is designed to assess the self-confidence levels of table tennis players. It consists of 7 items originally developed by Ibrahim et al., (2016) and subsequently refined by Yuda et al. (2022). The questionnaire's reliability has been confirmed through validation processes, yielding a high alpha coefficient of 0.85. Participants respond to each item using a Likert scale, where they indicate their level of agreement with statements ranging from "strongly disagree" (scored as 1) to "strongly agree" (scored as 4). This structured approach allows researchers to systematically gauge and analyze the self-confidence perceptions of the players involved in the study.

Cognitive Processing Speed

This test aims to measure the cognitive processing speed of table tennis players (Mohsen & Maleh, 2020). The test utilizes a table tennis table divided into five equal sections and a ball launcher that delivers 25 balls within 25 seconds. The balls are launched in random directions and colors. Participants must hit the balls towards the section of the table that matches the color of the ball launched by the robot (Huipang HP07). Each color has five balls, totaling 25 balls. Balls that land in a section that does not match their color are scored 1 point, balls that land in the correct color section are scored 2 points, and balls that go out are scored 0 points.

Topspin Stroke

Topspin accuracy was evaluated using a previously developed assessment tool, which has been demonstrated to provide valid and reliable data on topspin accuracy (Haryanto et al., 2023). During the test, participants were positioned at the center of the table. A feeder delivered the ball to the participants, who then executed topspin strokes aimed at pre-marked target areas on the table. Each successful stroke was scored based on accuracy, with points typically assigned as 3, 2, 1, or 0. A score of 0 was given when the ball failed to hit the table, while higher scores reflected greater accuracy in hitting the target areas.

Procedure

This research began with obtaining permission from Universitas Negeri Padang, Faculty of Sports Science, and the lecturer in charge of the table tennis course. After obtaining campus approval, researchers approached potential participants and requested their willingness to participate in the study. A team was assembled to assist in data collection, and they received training to ensure accuracy during the process. Before data collection commenced, researchers conducted health checks on all participants to confirm their readiness and good health. Participants were briefed in detail on the testing procedures and provided with simulated tests to ensure a clear understanding of the process. Prior to the actual tests, all participants completed a self-confidence questionnaire. They were then instructed to warm up and attempt both cognitive processing speed and topspin accuracy tests.

Statistical analysis

Descriptive statistics were computed to summarize the characteristics of the sample, both overall and for male and female participants separately. Normal distribution was verified using z-scores for skewness and kurtosis < 3.29. Hypothesis testing involved Pearson correlation analysis and linear regression to explore the associations between self-confidence, cognitive processing speed, and topspin stroke accuracy. Data were meticulously documented, and all analyses were conducted using the most recent version of SPSS software, with statistical significance set at $p < 0.05$.

Results

A total of 82 participants (67.1% male) provided valid data. Descriptive characteristics are shown in table 1. Male and female participants were of similar age but men were significantly taller and heavier women ($p < 0.01$). Average BMI was also significantly higher male compared to female participants ($p = 0.02$). While all female participants were classified as normal weight two men were classified as overweight and 1 man was classified as underweight. Years of training experience was also higher in male compared to female participants ($p = 0.02$) but there were no sex differences in topspin accuracy, self-confidence and cognitive processing speed.

Both, self-confidence and cognitive processing speed were significantly correlated with topspin accuracy (rSC = 0.430, rCPS = 0.374; $p < 0.01$). Sex-specific analyses revealed similar results among female and male participants (Women: rSC = 0.451, rCPSy = 0.428; Men: rSC = 0.431, rCPSy = 0.362). Both variables explained 26.3 % of the variability in topspin accuracy, with a more pronounced association of self-confidence with topspin accuracy compared to total processing speed (Table 2). The inclusion of training experience did not enhance the regression model and, therefore, only self-confidence and cognitive processing speed were included in the sex-specific analyses. Even though results were similar for men and women significant beta coefficients were only observed in men, which may be attributed to the small number of female participants.

Table 2. Linear regression analysis for topspin performance as independent variable for the total sample and separately for male and female participants

Indicators	R^2	Self-Confidence		Cognitive Processing Speed	
		beta	Sig.	beta	Sig.
Total Sample	0.263	0.362	<0.001	0.289	0.005
Female Participants	0.269	0.326	0.106	0.286	0.154
Male Participants	0.265	0.374	0.003	0.288	0.021

Discussion

The results of this research indicate a clear association between self-confidence and topspin stroke accuracy, highlighting the critical influence of self-confidence on the precise execution and efficacy of topspin strokes in table tennis. These findings underscore the importance of psychological factors in enhancing technical performance and overall competitive outcomes in sports. The significance of self-confidence in enhancing table tennis ball-hitting accuracy is well-established in the literature. Studies indicate a notable correlation between self-determined motivation, adaptive coping strategies, and performance levels among table tennis athletes, highlighting the pivotal role of intrinsic motivation in achieving superior outcomes (Martinent et al., 2018). Additionally, it has been noted through longitudinal studies that the dynamics of self-confidence tend to grow stronger over time, particularly during phases of psychological momentum experienced by athletes. This observation highlights the pivotal role of self-confidence not only in initial performance but also in its sustained enhancement throughout an athlete's competitive journey. Understanding these dynamics can provide valuable insights into how athletes can effectively manage and optimize their mental states to consistently achieve peak performance levels (Briki et al., 2012). Furthermore, the skill to discern the trajectory and spin of the ball in table tennis is essential for optimal performance. Research indicates that auditory cues play a significant role in this identification process, influencing players' abilities regardless of their training or experience levels. This highlights the universal importance of auditory perception in enhancing ball recognition and, consequently, overall game strategy and effectiveness (Santos et al., 2017). Therefore, the maintenance of elevated self-confidence levels is crucial in positively influencing a player's capacity to achieve precise ball placement in table tennis, ultimately shaping their overall performance outcomes. This underscores the pivotal role of self-confidence as a determinant factor in enhancing athletic proficiency and competitive success in the sport.

Our research results show a significant positive correlation between cognitive processing speed and topspin shot accuracy in table tennis. These findings support previous research suggesting that Athletes with strong cognitive abilities tend to exhibit superior performance in their gameplay. This relationship underscores the importance of cognitive training as a vital component in the holistic development of competitive athletes. Enhancing cognitive skills can lead to improved strategic decision-making and reaction times, thereby positively impacting overall athletic performance (Tsai et al., 2023). The cognitive abilities of athletes are integral to their sports performance, with professional athletes often demonstrating superior cognitive functions compared to their non-professional counterparts. This disparity highlights the significance of cognitive training in elevating athletes to elite levels, emphasizing its role in enhancing strategic thinking, decision-making, and overall gameplay (Hernández-Mendo et al., 2019). The ability to process information swiftly is crucial not only in academic settings but also in sports, where athletes must make rapid and accurate decisions. This quick decision-making capability is essential for adapting to dynamic game situations, ultimately contributing to superior athletic performance (Lovett et al., 2022). Enhanced cognitive processing speed enables players to anticipate opponents' movements more effectively, resulting in greater accuracy when executing topspin shots. Sustaining high cognitive performance throughout a match further contributes to maintaining accuracy and speed, ensuring consistent and superior performance over time (Díaz-García et al., 2023).

A study found that children with high cognitive processing speed and good muscular fitness exhibit significantly shorter cognitive reaction times compared to those with slower cognitive processing speed (Tsai et al., 2020). Research on the motivation for learning, physical activities, and intellectual development in table tennis players indicated that incorporating chess-pong elements enhanced the players' cognitive abilities. Additionally, the inclusion of chess elements in training positively affected the psychological and pedagogical conditions, thereby promoting a high level of motivation for participating in this sport (Stovba et al., 2023).

The findings from this research offer valuable applications for training and coaching in table tennis. Coaches may consider incorporating exercises that specifically enhance cognitive processing speed, such as reaction drills and decision-making scenarios. A comprehensive approach to training that integrates cognitive and self-confidence dimensions can further elevate a player's overall performance. By understanding the intricate relationship between psychological factors and technical skills, coaches can develop tailored training programs that meet the individual needs of table tennis players. However, it is important to note that this study did not include professional athletes, and further research is necessary to explore these associations at higher levels of play. Additionally, self-confidence was not assessed in real match situations. Employing other methods, such as direct observation during matches or match simulations during training, could provide a more thorough understanding of this concept and its impact on playing performance. Limitations of this study include a small participant sample size and a lack of variation in playing ability. Differences in rackets used may also influence topspin performance, despite participants reporting comfort with their respective rackets.

Conclusion

The topspin shot is an essential offensive maneuver in table tennis, and achieving accuracy in its execution is crucial for athletes aiming for success. This research investigated how cognitive processing relates to the precision of topspin shots, alongside examining the influence of self-confidence on topspin accuracy. Recognizing the direct correlation between cognitive abilities and topspin performance underscores the importance for coaches to integrate these aspects into their training regimens, which should encompass short-term, medium-term, and long-term strategies. Coaches can design specific training programs to enhance athletes' cognitive processing speed and self-confidence, incorporating exercises in quick reaction and decision-making scenarios. A holistic approach integrating psychological aspects such as stress management and confidence development is also essential in training to consistently improve athletes' topspin performance. Ongoing evaluation and detailed feedback on athletes' psychological and cognitive progress will guide the development of effective long-term training programs, ensuring athletes can achieve their optimal potential in competition. Recommendations for future research include conducting comparative studies between professional and non-professional table tennis athletes to gain deeper insights into the relationships among cognitive processing speed, self-confidence, and topspin performance. Furthermore, expanding research to explore the role of emotional intelligence in the context of real match situations, and investigating other physical factors influencing topspin technique such as physical strength and movement techniques, is warranted. The use of direct observation methods during matches or match simulations is also recommended to obtain a more comprehensive understanding of the complex interactions among psychological, cognitive, and technical factors in athletes' performance in competition.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Впевненість у собі та когнітивна швидкість: Ключові предиктори визначення точності виконання топ-спіну в змаганнях з настільного тенісу

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

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Історія питання. Гравці з настільного тенісу часто використовують топ-спін з метою досягнення результату. Для багатьох спортсменів цей удар має вирішальне значення для перемоги, що робить його фаворитом серед гравців. Існує велика ймовірність того, що виконання точних ударів топ-спін ускладнить опонентам повернення м'яча. Як наслідок, гравці, які можуть зберігати точність удару топ-спін протягом тривалого часу, мають більше шансів на здобуття перемоги в матчах.

Мета дослідження. Метою цього дослідження було вивчити зв'язок між впевненістю у собі (ВС) і швидкістю когнітивної обробки (ШКО) з точністю виконання топ-спіну (ТТ) в настільному тенісі.

Матеріали та методи. У рамках дослідження застосовано кореляційний метод з кількісним підходом. Загалом у дослідженні взяли участь 82 учасники (вік: 20,00 ± 0,60 років). Збір даних щодо точності виконання топ-спіну проводився за допомогою тесту з визначення точності виконання топ-спіну з подальшим застосуванням опитувальника для визначення рівня впевненості в собі та тесту з оцінки швидкості когнітивної обробки інформації. З метою встановлення зв'язку між змінними використовували кореляційний аналіз Пірсона та лінійну регресію.

Результати. Результати цього дослідження показують (1) позитивний взаємозв'язок між впевненістю в собі і точністю виконання топ-спіну ($r = 0{,}430$, $p < 0{,}05$); (2) позитивний взаємозв'язок між швидкістю когнітивної обробки і точністю виконання топ-спіну ($r = 0{,}374$, $p < 0{,}05$).

Висновки. Точність виконання топ-спіну залежить від швидкості когнітивної обробки та впевненості в собі. Отже, тренери повинні враховувати зазначені фактори задля поліпшення результативності виконання топ-спіну в настільному тенісі. Результати цього дослідження можуть суттєво вплинути на тренувальні програми, де тренування ментальних навичок, як-от підвищення впевненості в собі та поліпшення швидкості когнітивної обробки, слід інтегрувати в технічні

та тактичні режими тренування. Такий підхід дозволить спортсменам не тільки вдосконалити свої фізичні навички, але й зміцнити психологічну стійкість, що в кінцевому підсумку призведе до покращення результативності у змагальних матчах.

Ключові слова: інтелектуальна здатність, емоційний стан, когнітивна реакція, влучність удару, точність в ракетковому виді спорту.

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Original Scientific Article

Ascertaining the Impact of Skill-Based, Intensive Training on the Cardiovascular and Muscular Performance of Male Hockey Players

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

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Abstract

Objectives. The study aimed to investigate the impact of skill-based maximal-intensity interval training on cardiovascular and muscular performance variables in male hockey players.

Materials and methods. For this study, a group of 24 male hockey players were carefully selected. The participants were divided into two groups: SBT (n = 12) and CG (n = 12). A 12-week programme was carried out, comprising skill-specific, high-intensity interval training sessions that took place three times per week. Data was gathered prior to and following the study. The variables selected for evaluating consisted of a 20-meter, 30-meter, and 50-meter sprint, along with agility, speed endurance, and cardiovascular endurance. Pre and post data were subjected to statistical analyses.

Results. The findings of statistical analyses indicate a significant positive impact due to performing the 12-week skill-based intensive training. The SBT group consistently demonstrated superior performance compared to the CG group. This was evident through their significantly faster completion times in distances of 20 m, 30 m, and 50 m, as well as their agility tasks. Additionally, the SBT group achieved higher scores in endurance measures. The effect sizes observed in the study were quite significant, indicating substantial differences between the groups. Furthermore, it is noteworthy that the CG group did not exhibit any marked changes from the pre-test to the post-test in any measure.

Conclusions. After a period of 12 weeks, it has been observed that skill-based maximal-intensity interval training leads to significant improvements in both anaerobic and aerobic performance. This training is essential for athletes as they prepare for the end of the season. According to the study, it is recommended that hockey and other coaches focus their efforts on skill-based maximal-intensity interval training. While this study did not specifically assess technical abilities, it found that this training technique significantly enhanced physical performance. This research and training could prove advantageous for athletes and coaches who prioritise honing their skills.

Keywords: skill-based training, HIIT, hockey, physical performance, training method.

Introduction

Hockey is a team sport that involves a combination of intense activities like sprinting, dribbling, hitting, and passing, along with periods of lower intensity like jogging and walking for recovery (Harry & Booysen, 2018). Team sports that involve intense, intermittent activity demand athletes to possess a strong foundation of physical performance attributes, including agility, speed, and both aerobic and anaerobic power (Gamble, 2013). Various training methods have been employed to enhance the overall physical performance in the sport of hockey. In addition, the compatibility of these training models with the technical and tactical skills of sport can greatly enhance the effectiveness of the training (Timmerman, Savelsbergh, & Farrow, 2019). Coaches and researchers have shown a growing preference for skill-based and high-intensity training methods, which are known for their effectiveness and efficiency (Fernandez-Fernandez, Sanz, Sarabia, & Moya, 2017). The development of technical skills, tactical awareness, and physical conditioning is all impacted simultaneously (Gabbett, 2008).

The effectiveness and systematic nature of skill-based exercises make them an ideal training method (Karahan, 2020). This approach caters to both young or non-specialized players, allowing them to develop technical skills, as well

as specialized players who can refine and maximize their skills in competitive settings. High-intensity, intermittent training has been shown to have remarkable effects on skeletal muscle and metabolic capacity and adaptation (Kohn, Essén-Gustavsson, & Myburgh, 2011; Perry, et al., 2008). When skill-based training is conducted at a high or maximum intensity, it offers players ample opportunities to enhance their technical, tactical skills, and physical performance simultaneously (Fernandez-Fernandez et al., 2017). Coaches often employ skill-based variations to guide players towards specific physical and technical objectives. Lately, there has been a widespread adoption of skill-based training programmes to enhance technical and physical performance, especially in team sports (Hammami, Gabbett, Slimani, & Bouhlel, 2018). Nevertheless, research has yet to definitively prove the effectiveness of these training programmes compared to traditional methods (Karahan, 2020).

Several recent studies have been dedicated to examining skill-based training methods carried out at high or maximum intensity (Karahan, 2012; Sü, 2015). The study revealed that rigorous training focused on developing specific skills had a notable influence on the speed, agility, and aerobic and anaerobic power of female futsal players (Karahan, 2012). These effects were comparable to those observed in players of volleyball and handball (Sü, 2015). A different study conducted by (Gabbett, 2008). analysed the differences observed prior to and following the training period. Based on the findings, it is evident that skill-based training significantly improved the speed and agility of young volleyball players. The analysis of jumping, change of direction, and aerobic capacity before and after the intervention clearly demonstrates a steady improvement in young football players (Sanchez-Sanchez et al., 2019).

The success of a player is heavily influenced by their level of performance and the amount of effort they put into engaging with the ball. However, there is still uncertainty surrounding the scientific understanding of how these variations affect the physical performance of a player or team (Timmerman et al., 2019). Prior research in the field has primarily concentrated on analysing the physical capabilities of male hockey players and the effects of training regimens on both aerobic and anaerobic factors (Sharma & Kailashiya, 2018). This study proposed that by incorporating high-intensity training into training programmes using ball-specific drills and small-sided games, enhancements could be observed in both aerobic and anaerobic performance, along with technical proficiency. The purpose of this study was to examine how skill-based maximal intensity interval training affects the aerobic and anaerobic performance of male hockey players. The study's findings have the potential to provide valuable guidance to coaches and players as they strive to improve their training programmes.

Materials and Methods

Participation

A group of twenty-four skilled university hockey players, all belonging to the same team, participated in this study during their participation in the university games. Participants were divided into two groups: the skill-based group (SBT) and the control group (CG). We estimated the sample size using G*Power software (version 3.1). Based on the given data, a sample size of 12 was determined. The partial effect size was found to be 0.02, with a power of 0.08 and a P value of 0.05 for two group measurements. Additionally, a correlation of 0.05 was observed. Table 1 presents the demographic characteristics of the groups.

Subjects with any acute or chronic disease, pain indicators, or those under medical treatment were excluded from the study based on the eligibility criteria. In addition, participants who sustained injuries during the experiment were also excluded. All participants successfully completed a minimum of 80% of the total sessions and consistently fulfilled all of the test procedures before and after the study. (4) The subject did not participate in any official matches during the study period. Before obtaining written informed consent, all players, parents, and coaches received comprehensive information about the research procedure, including any potential risks, benefits, and requirements. Flow Table 2 presents a concise summary of the criteria for participation.

Procedure

This study aimed to examine how SBT affects the physical performance characteristics of young hockey players. A study was conducted utilising two groups, SBTG or CG, over a period of 12 weeks. The study followed a parallel randomized, controlled longitudinal design. Both groups completed a total of 36 units, with each week consisting of 3 training units. Three orientation sessions were conducted a week prior to the initial evaluation to acquaint the participants with the tests and exercises utilized in this study. In addition, the researchers offered clear instructions and visual examples during the intervention to ensure that the correct technique was consistently followed. The assessments conducted before and after the training duration consisted of a thorough set of evaluations. These evaluations included tests such as the 20 m, 30 m, and 50 m sprint tests, the T-run test, the 45 Second sprint, and the Cooper 12 m walk/run test. To ensure consistency, the same assessors performed all of the test measurements.

The physical performance test was carried out both before and after the 12-week training programme, following the principles of measurement. The tests were conducted

Table 1. Demographic characteristics of groups

	Age (year) means ± SD	Experience (year) means ± SD	Height (cm) means ± SD	Weight (kg) means ± SD
SBT(n = 12)	20.167 ± 1.029	7.916 ± 1.240	164.834 ± 5.670	59.483 ± 2.667
CG (n = 12)	20.416 ± .996	8.167 ± 1.193	166.083 ± 5.712	56.483 ± 2.006

SBT = skill-based training, CG = control group

in the morning from 6.30 to 8.00 am in a controlled environment, namely an indoor pitch at SRM University in Chennai. Before and after the test applications, the players engaged in a 10-minute warm-up and cool-down routine. To ensure fairness, we used an online resource[1] to randomly assign subjects. The training sessions were closely supervised by certified hockey coaches and a conditioning specialist to ensure that SBT was executed with utmost effort. Additionally, a thorough warm-up and cool-down exercise were included. The coaches and researchers provided clear instructions and encouragement to all players during tests, aiming to maximize their efficiency in handling workloads.

20 m sprint test: A photocell device was used to measure the sprinting speed of the players. The device was positioned at both the start and finish lines, which were 20 metres apart. The players performed the 20-meter sprint with great determination, starting from a stationary position. The test was performed on three separate occasions, with a 90-second rest period between each repetition. We recorded the running time that produced the most optimal result. The measurement test-retest reliability for the 20-m sprint test resulted in an intra-class correlation coefficient of 0.88 (Haghighi, Hosseini, Askari, Shahrabadi, & Ramirez-Campillo, 2024; Wheeler Botero et al., 2023).

30 m sprint test: A speed measurement was taken using a 30 m sprint test. Cones were strategically positioned 30 metres apart, forming a path between the starting and finishing lines for the test. Participants race with all of their strength from the starting line to the finishing line. The stopwatch began timing when the participant initiated the run and stopped when the participant completed the run. Every participant was given three chances to showcase their skills, with their quickest time being recorded as their performance (Coelho et al., 2007).

50 m sprint test: A speed measurement was taken through a 50 m sprint test. Cones were strategically positioned 50 metres apart, forming a path between the starting and finishing lines for the test. Participants race with great speed from the starting line to the finishing line. The stopwatch began timing when the participant initiated the run and stopped when the participant completed the run. Every participant was given three chances to showcase their skills, with the quickest time being noted as their performance (Wheeler Botero et al., 2023).

The 45-second run test: The 45-second run test is a method used to evaluate an individual's capacity for speed endurance. The participant gracefully moved back and forth along a 20-meter track, completing the task within a 45-second time frame. Starting from one end, the participant swiftly accelerates to the opposite end, lightly touches the line with one hand, swiftly turns and sprints back, repeating this shuttle run pattern as many times as possible until the time runs out. Precise timing using a stopwatch or timer is essential. The score is determined by the number of shuttles completed within the allotted time, indicating a measure of speed endurance fitness (Wood, 2020)

Change of direction ability test: The T-run test was used to evaluate the players' ability to change direction (CoD). The test (Figure 1) requires the measurement of the player's speed during different directional changes, such as forward sprinting, left and right shuffling, and returning to the start line. The test was performed on two occasions, separated by a 2-minute active recovery interval. An electronic timing system positioned at the starting line recorded the performance that produced the most favourable outcomes. The test-retest reliability of measurement for the T-run test was determined to be 0.95, indicating a strong level of consistency (Sassi et al., 2009).

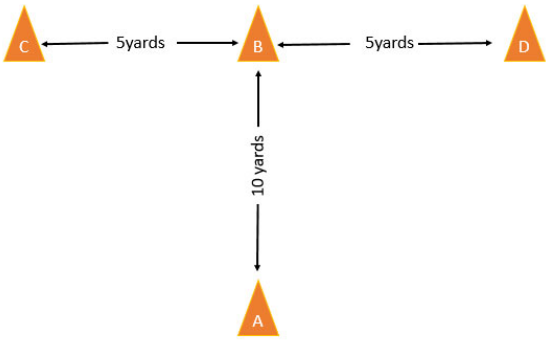

Fig. 1. Shows the T- run test

The Cooper 12-minute: The Cooper 12-minute walk or run test is a widely recognized and commonly employed evaluation of cardiovascular endurance fitness. Participants are given clear instructions to maximize their distance covered in a 12-minute time frame. They have the option to choose between walking or running, and the course is carefully measured and flat. Prior to commencing, it is crucial for participants to engage in a thorough warm-up routine in order to minimize the risk of sustaining any injuries. From the moment the test commences, they gracefully maintain a consistent rhythm, with the goal of exploring as much territory as they can. The distance covered is measured and recorded at the end of the 12 minutes (Kumar & Zemková, 2022).

Training programmers

The programme focuses on enhancing the physical and skill performance of hockey players through skill-based HIIT training. The timing of these sessions was consistent, starting at 6.30 am and ending at 8.00 am. SBTG was carefully guided by a coach and researcher, ensuring that they underwent a thorough warm-up consisting of 10 minutes of general and specific exercises, including stretching. Following a series of low-intensity dribbling, passing, and hitting exercises, a 10-minute cool-down routine is carried out.

Throughout the intervention period, players were guided to give their utmost effort during their activity. The researcher and coach provided instructions to ensure high motivation. The SBT sessions were held three times a week, specifically on Mondays, Wednesdays, and Fridays. The researcher supervised these sessions. The distribution of the training programme for the SBT group across the days of the week can be seen in Table 2. The players engage in a variety of skill exercise training and small-sided games, all involving the ball. Table 3 presents the 12-week training intervention. The evaluation of training intensity was measured using the CR-10 Borg's scale (Shariat et al., 2018) in training interventions. This scale quantifies the rating of perceived exertion (RPE). Prior to the interventions, the players were introduced to the scale. Each player was asked to rate their perceived level of effort exerted during

[1] https://random-allocation-software.software.informer.com/2.0

Table 2. Time table for implementing the training program

Groups	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
SBTG		+		+		+	
CG							

SBTG = Skill-based training group, CG = Control group

Table 3. Show the 12-week Training Schedule

Weeks	No.of repetition	Duration of repeat	Recovery time B/W repetition	Recovery time b/w exercise section	Total duration
1-3 weeks	4	25 s	30 s	4 min	35-40 minutes
4-6 weeks	5	25 s			
7-9 weeks	6	20 s			
10-12 weeks	7	20 s			

the intervention. The players were questioned about their thoughts on the intervention's intensity and were asked to provide an evaluation. The responses were diligently documented on a sheet once the inquiry had been addressed.

The SBT group executed a customary 10-minute general systemic warm-up, complemented by dynamic range of motion exercises, and concluded with a 10-minute cool down consisting of jogging and stretching, both prior to and after all training sessions. The primary training sessions consisted of various skill-based exercises such as dribbling and sprinting (Station 1, Fig. 2), Passing (Station 2, Fig. 3), Hitting and shooting the goal (Station 3, Fig. 4), and 10-minute small-sided games (on pitches measuring 30 × 20 with 6 players on each team) played with maximum effort.

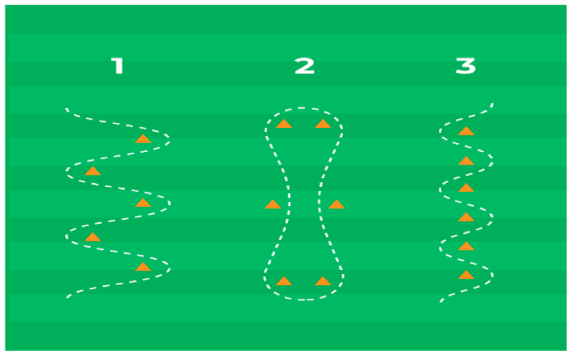

Fig. 2. Dribble and sprint.
Note: station 1: To perform zig-zag, W dribbling, straight dribbling, dribbling in Pairs, figure 8 dribbling.1v1dribbling (All the exercises to perform maximum speed and perfection)

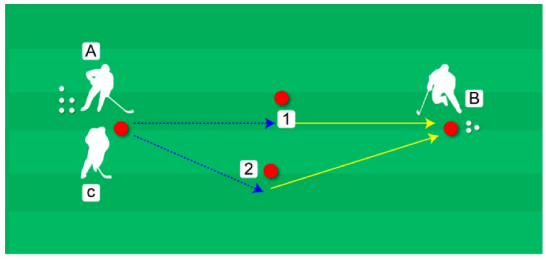

Fig. 3. Passing
Note: station 2: To perform pass and move, shuttle passing, dynamic passing, 3v1keepaway, overlapping, passing really. (All the exercises to perform maximum speed and perfection)

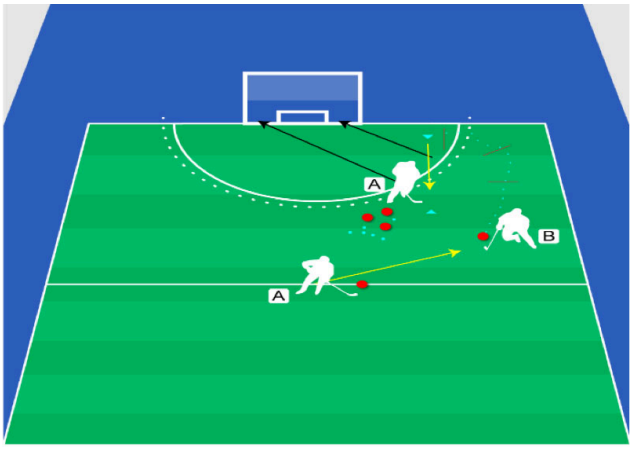

Fig. 4. Hitting
Note: station 3: To perform Moving Target Practice, pass and hit, hitting on the move, shooting and hitting combo, passing and hitting in motion. (All the exercises to perform maximum speed and perfection)

Statistical analyses

The analysis of data normality began with the Shapiro-Wilk test. After completing the initial step, we utilized the analysis of covariance (ANCOVA) to investigate the effectiveness of the training programmes. We included baseline measurements as covariates to conduct a more detailed analysis. Afterwards, we used Cohen's d to measure the effect size by converting the partial eta-squared values obtained from the ANCOVA result. Additional analysis included evaluating performance changes within the same group before and after the intervention, using a paired sample t-test. The effect sizes obtained from these tests were categorized based on Cohen's criteria, which provide a clear understanding of the impact of the training. The categories include small, medium, and large, with corresponding values. The reliability of these measures over time was confirmed through the intra-class correlation (ICC), particularly using a 3, 1 model, which ensured the consistency of our findings. The mean values and standard deviation were carefully compiled to provide a thorough overview for initial assessment. Throughout the study, a high level of significance was maintained at $p < 0.05$ to ensure scientific accuracy.

Results

Presented in Table 4 are the baseline results and the observed changes following a 12-week period of high-intensity skill training for aerobic and anaerobic performance in hockey for the SBT and CG.

In order to determine any significant changes between the pre-test and post-test scores of the variables being studied, a paired t-test is conducted. Prior to this, the normality assumptions are checked using the Shapiro-Wilk test, which confirms that the data follows a normal distribution. Tests are conducted individually for each group. Remarkable progress was evident in all areas within the SBT group, as observed from the initial assessment to the final evaluation. Participants demonstrated significant improvements in various physical variables, including reductions in time for distances of 20 m, 30 m, and 50 m, as well as improvements in agility, speed endurance, and cardiovascular endurance. The improvements observed in the measures were found to be statistically significant, with p-values less than 0.05. This suggests that the training programme had a significant impact on the observed changes. The effect sizes displayed a range of magnitudes, indicating that although all measures showed improvement, the extent of improvement varied across tasks. The most significant effects were observed in speed endurance and cardiovascular endurance. A comparison between the SBT and CG groups was conducted using ANCOVA, with the covariates controlled. Notably, significant main effects of the group were observed across all variables. The SBT group consistently demonstrated superior performance compared to the CG group. This was evident through their significantly faster times in distances of 20 m, 30 m, and 50 m, as well as their agility tasks. Additionally, the SBT group achieved higher scores in endurance measures. The effect sizes observed in this study were quite significant, with values ranging from 0.205 to 0.657. These findings highlight the substantial differences that exist between the groups being compared. It is important to note that the CG group did not exhibit any significant changes from the pre-test to the post-test in any measure. This confirms that the improvements observed in the SBT group were not due to simple test-retest effects, but rather to the specific effects of the training programme. The findings highlight the effectiveness of the SBT intervention in improving physical performance when compared to a control condition.

Discussion

This study aimed to evaluate the effects of a sprint-based training programme (SBT) on the physical performance of male hockey players, in comparison to a control group (CG). The results show significant improvements in the SBT group across all measures, including significant reductions in sprint times at 20 m, 30 m, and 50 m, enhanced agility and speed endurance, and increased cardiovascular endurance from pretest to posttest.

The objective of the present study was to evaluate the effects of a rigorous, skill-focused interval training programme on the cardiovascular and muscular performance of male hockey players. This study investigates the effects of skill-based training and intensive interval training on the physical performance characteristics of hockey players in the pre-season period. The researchers conducted a range of tests to measure different parameters, such as sprint tests at distances of 20 m, 30 m, and 50 m, the T-run test, the 45 Second sprint, and the Cooper 12 m walk/run test. According to the study findings, a twelve-week skill-based intensive interval training programme showed a notable improvement in all tested physical performance characteristics ($p < 0.05$). The results unequivocally show the efficacy of the SBT intervention in improving the performance of hockey players.

There was a significant improvement in the time taken for various physical variables, such as the 20 m, 30 m, and 50 m sprints, agility, and speed endurance, from the initial assessment to the final assessment. In addition, there was a significant improvement in cardiovascular endurance. There was a wide range of effect sizes, ranging from small to large. The most notable impacts were seen in speed endurance and cardiovascular endurance. Surprisingly, the control group (CG) did not exhibit any significant

Table 4. Displays the responses of SBT and CG in relation to the physical performance characteristics of male hockey players

Variable	SBT(n = 12) means ± SD		Effect Size	Magnitude	CG (n = 12) means ± SD		F	η^2
	Pre-test	Post-test			Pre-test	Post-test		
20 m	3.362 ± 0.121	3.263 ± 0.177*	0.621	Medium	3.388 ± 0.125	3.384 ± 0.118	8.685*	.293
30 m	4.798 ± 0.314	4.558 ± 0.286*	0.779	Medium	4.783 ± 0.313	4.844 ± 0.426	11.125*	.346
50 m	7.148 ± 0.117	7.087 ± 0.093*	0.571	Medium	7.126 ± 0.099	7.224 ± 0.204	5.401*	.205
Agility	10.841 ± 0.392	10.747 ± 0.338*	0.259	Small	10.826 ± 0.398	10.871 ± 0.448	11.335*	.351
Sped. Endurance	4.875 ± 0.311	4.533 ± 0.331*	1.054	Large	4.900 ± 0.461	4.842 ± 0.523	22.293*	.515
Cardiovascular endurance	2285.000 ± 340.20	2572.500 ± 336.401*	0.848	Large	2297.500 ± 325.761	2286.250 ± 322.117	40.147*	.657

*Significant at 0. 05 level of significance

changes across any measures from the pre-test to the post-test. A study conducted by (Karahan, 2012) revealed that skill-based maximal intensity interval training had notable impacts on the aerobic and anaerobic performance variables of female futsal players. Significant improvements were observed in the average anaerobic power, fatigue index, and VO_2max of the TG, with increases of 10.7 %, 22.1 %, and 9.6 % ($p < 0.05$), respectively. On the other hand, the control group did not show any notable changes.

The performance of anaerobic activities is primarily influenced by the composition of muscle fibres and the capacity of glycolytic enzymes in skeletal muscles. These factors are primarily influenced by an individual's genetic composition. However, it is crucial to consider the possibility of training as well (Roberts, Billeter, & Howald, 1982). Enhancing anaerobic performance is impacted by a range of factors, such as the intensity and duration of training, as well as the trainability of individual players. Previous studies have shown that integrating high- or maximal-intensity training methods can improve anaerobic performance variables in team sport players (Sirotic & Coutts, 2007). These studies suggest that enhancing anaerobic performance can give players an edge in consistently and effectively executing their technical skills and motor abilities during competitions.

Previous studies have consistently demonstrated that participating in high- or maximal-intensity interval training can result in notable enhancements in the aerobic performance of team sport athletes, even over a relatively brief period. A study conducted by (Tabata et al., 1996). found that participating in high-intensity training for six weeks resulted in a significant 7 % increase in VO_2max. In a separate study, (Dupont, Akakpo, & Berthoin, 2004) discovered that incorporating high-intensity interval training into the regular training season resulted in a significant 18 % improvement in maximal aerobic speed. A study conducted by (Sporis, Ruzic, & Leko, 2008), (Sirotic & Coutts, 2007) and (Tabata et al., 1997) has demonstrated that participating in high-intensity exercise can greatly improve aerobic capacity and anaerobic power. The results are consistent with the upward trends observed in the current study.

According to a study conducted by (Karahan, 2020), the results indicate that skill-based training may be more effective in improving the preseason physical performance of young male soccer players when compared to small-sided games. This study offers valuable insights for coaches and researchers concerning a twelve-week intervention period. The study focuses on the beneficial effects of skill-based, intensive interval training on the cardiovascular and muscular performance of male hockey players.

Conclusions

Our research indicates that following a 12-week period of skill-based maximal-intensity interval training, significant improvements were observed in both anaerobic and aerobic performance. This training schedule is of utmost importance for athletes, especially during the critical phase of preparation before the start of the competitive season. It is evident that coaches of hockey and other sports should prioritise skill-based maximal-intensity interval training as their primary training approach. According to the study's findings, it can be concluded that this training approach is very effective in improving physical performance, even though it does not directly evaluate technical skills. The current research and training methodology has significant potential for athletes and coaches who value skill-focused training as a way to improve physical performance.

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Conflict of Interest

The author states that there are no conflicts of interest regarding the publication of this manuscript.

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З'ясування впливу навичко-орієнтованих інтенсивних тренувань на продуктивність серцево-судинної та м'язової систем чоловіків-хокеїстів

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

Реферат. Стаття: 8 с., 4 табл., 4 рис., 26 джерел.

Мета дослідження. Мета дослідження полягала у вивченні впливу навичко-орієнтованих інтервальних тренувань максимальної інтенсивності на показники продуктивності серцево-судинної та м'язової систем у хокеїстів-чоловіків.

Матеріали та методи. В рамках дослідження проведено ретельний відбір групи з 24 хокеїстів-чоловіків. Учасники були розділені на дві групи: НОТ — навичко-орієнтоване тренування (n = 12) та КГ — контрольна група (n = 12). Програма тривала 12 тижнів, проводилась тричі на тиждень і включала високоінтенсивні інтервальні тренування (ВІІТ), спрямовані на розвиток конкретних навичок. Збір даних здійснювався перед початком і після завершення дослідження. З метою оцінки було обрано наступні показники: спринтерський біг на 20, 30 і 50 метрів, а також спритність, швидкісна витривалість і витривалість серцево-судинної системи. Отримані дані на перед- та післятестовому етапах дослідження підлягали застосуванню статистичних аналітичних методів.

Результати. Результати проведення статистичних аналітичних методів вказують на значний позитивний вплив, досягнутий завдяки виконанню 12-тижневого навичко-орієнтованого інтенсивного тренування. Група НОТ незмінно демонструвала кращу результативність порівняно з КГ. Про це свідчить значно швидший час подолання дистанцій 20 м, 30 м і 50 м, а також виконання завдань на спритність. Крім того, група НОТ досягла вищих результатів за показниками витривалості. Розміри ефекту, що спостерігалися в дослідженні, виявились досить суттєвими, що вказує на наявність істотних відмінностей між групами. Також варто зазначити, що в КГ не було зафіксовано виражених змін у жодному з показників на період від перед- до післятестового етапів дослідження.

Висновки. Після закінчення 12-тижневого періоду спостерігалося, що навичко-орієнтовані інтервальні тренування максимальної інтенсивності, призводять до значного покращення анаеробної та аеробної продуктивності. Такі тренування є важливою складовою підготовки спортсменів до завершення сезону. Згідно з дослідженням, тренерам з хокею та інших видів спорту рекомендується зосередити свої зусилля на проведенні навичко-орієнтованих інтервальних тренувань максимальної інтенсивності. Попри відсутність спеціальної оцінки технічних здібностей, дослідження встановило, що зазначена методика тренувань сприяє суттєвому підвищенню фізичної працездатності. Представлене дослідження і тренування можуть стати корисним інструментом для спортсменів і тренерів, які надають пріоритет відточуванню своїх навичок.

Ключові слова: навичко-орієнтоване тренування, ВІІТ, хокей, фізична працездатність, метод тренування.

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Original Scientific Article

Olympics: Improving the Competition Strategy in Each Skill Technique of Elite Swimmers for the 400 meters Freestyle

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Abstract

Background. In swimming championships, strategy setting is considered to be the main factor, especially in the middle and long-distance events. Implementing a strategic change can indirectly affect the final results.

Objectives. The study aimed to find out whether there were any significant differences in reaction time (RT), final time (FT), and strategy for each split time (ST) in the men's and women's 400 meters freestyle events at the Olympic Games held in Tokyo (2021), Rio de Janeiro (2016), and London (2012).

Materials and methods. This study used quantitative methods with a sample size of 48 athletes. The data source included using the secondary data. Descriptive statistics are presented in the form of means and standard deviations. The Shapiro–Wilk test was used to test the normality of the data. To compare RT, FT, and ST data, the one-way ANOVA test was conducted. The linear regression test was used to determine the effect of RT on the first ST.

Results. The findings of this study indicate that there were differences in the RT of male athletes during the 3 Olympics. The study also revealed variations in average speed. In general, swimmers accelerated their speed at ST1 and ST8. This occurred at the Tokyo 2021 and Rio de Janeiro 2016 Olympics, while at the London 2012 Olympics, swimmers accelerated their speed only at ST1. Additionally, the results demonstrated that RT had an influence of 0.381 (14 %) on the first ST in male athletes, whereas the influence in female athletes was less marked – 0.066 (4 %).

Conclusions. This study concludes that ST1 and ST8 are the most crucial components in the 400 meters freestyle swimming for both male and female athletes. Coaches and athletes must be very careful in carrying out special training at the tapering stage so that athletes can achieve the right time to produce the best performance.

Keywords: swimming strategy, performance, analysis, olympics.

Introduction

In swimming competitions where a small difference of milliseconds can determine success especially in the Olympic championships (Post et al., 2020; da Silva, 2019). By optimizing the performance speed athletes can achive their best performance (Bishop et al., 2009). To achive the best performance in swimming really depends on several factors such as biomechanics, swimming strategy, physiology and physicology (Ben-Zaken et al., 2022; Gonjo & Olstad, 2020; Meggs & Chen, 2019; Price et al., 2024). Small mistakes made by swimmers in making disproportionate changes in movement can cause enormous hydrodynamic resistance in changing speed (Pramono et al., 2023; Takagi et al., 2023). These obstacles cause a loss of energy in swimmers that should be used to accelerate swimming (Fone, 2022).

The 400-meter freestyle swimming event is a middle-distance race lasting approximately 3.5 to 5 minutes, characterized by a predominantly aerobic energy contribution of about 88 % (Correia et al., 2020). This race number requires strength and VO_2max that is high enough to be able to maintain performance while swimming (Sokołowski,

Bartolomeu et al., 2022; Sokołowski, Strzała, & Żegleń, 2022). This number is supported by a combination of contribution of lactic acid and anaerobic glycolysis (Campos et al., 2017). Therefore the coach must understand what energy is used in athlete during the race.

Planning the right competition strategy is a major factor and is considered very important in swimming championships (Polach et al., 2021). Athletes who have reached their elite level have an excellent strategy (Born, Lomax, & Romann, 2020). Although there are slinght physiological differences from other athletes, winning or losing athletes depend on their ability to regulate energy to prevent premature fatigue (Skorski & Abbiss, 2017). In a race swimmers may try to disrupt their copetitors race strategy by accelerating at the start or slowing down earlier than expected, this makes some swimmers position themselves in such a way to avoid the turbulence strategy created by their competitors (McGibbon et al., 2018).

Changes in strategy in swimming competitions can indirectly affect the speed of movement, therefore it is im-portant for a coach to update his understanding of startegies in starting, half time, turning, and time before the finish (Morais et al., 2019; Morais, Barbosa, Forte et al., 2021). In Indonesia, there are still many athletes and coaches who do not know the strategy for swimming in the middle and long distances, so athlete just swim as fast as possible to the finish line without understanding how much energy they are using. The coach must also be careful in applying the understanding of race analysis to the athlete's strategy, because the strategy in the old championships may have been different from the current championship strategy (Gonjo & Olstad, 2020).

Materials and Methods

Study Participants

This research was conducted using quantitative research method, where the number of samples taken 48 athletes with each number consisting of 8 athletes. To obtain a respresentative sample, athletes who won position 1-8 in the final match were chosen from number 400 meters freestyle in 3 Olympic London 2012, Rio 2016 and Tokyo 2021 (table 1).

Table 1. Profile athlete male and female in 400-meters freestyle

Rank	Sex	London 2012 (Age)	Rio 2016 (Age)	Tokyo 2021 (Age)
1	Male	YS (20 years)	MH (20 Years)	AH (18 Years)
	Female	AS (22 Years)	KL (19 Years)	AT (20 Years)
2	Male	TP (22 Years)	YS (24 Years)	JM (26 Years)
	Female	CM (22 Years)	SS (22 Years)	SH (23 Years)
3	Male	PV (28 Years)	GD (21 Years)	KS (21 Years)
	Female	BB (23 Years)	EM (22 Years)	PO (21 Years)
4	Male	YH (17 Years)	CD (27 Years)	HM (24 Years)
	Female	MF (17 Years)	FP (28 Years)	JY (19 Years)
5	Male	CD (23 Years)	CJ (25 Years)	FA (24 Years)
	Female	FP (23 Years)	DS (19 Years)	KL (24 Years)
6	Male	GK (24 Years)	JG (20 Years)	GD (26 Years)
	Female	VA (21 Years)	BB (27 Years)	BS (21 Years)
7	Male	DC (30 Years)	DM (24 Years)	EW (21 Years)
	Female	CM (26 Years)	MC (22 Years)	FP (32 Years)
8	Male	RN (22 Years)	JP (21 Years)	JM (19 Years)
	Female	KP (22 Years)	CB (21 Years)	MW (27 Years)

Data Collection

In this study, data on reaction time (RT), Split Time (ST) and Final Time (FT) were taken from the website[1] used as secondary data. This research sample also does not use an objective from because the data has been verified through the official website of the Olympic.

Statistical Analysis

The descriptive statistics presented are the mean and standart deviation, test the normality of the data using Shapiro-Wilk test. In comparing data between Olympiads, the multi-comparasion One-Way ANOVA method was used to verify RT, ST, and FT between difference Olympiads. Linear regression is used to determine how much influence RT has on the first ST.

Results

Table 2 above shows the results of the Shapiro-Wilk normality test on male and female athletes in the 400-meter freestyle during the 3 Olympic Games. All results show that both male and female athletes in each round have normal scores with a value above 0.05.

Table 2. Description of normality tes ton splite time

Sex	Olympic	Shapiro-Wilk								Information
		df	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	
Male	Tokyo 2020	8	0.207	0.363	0.624	0.871	0.557	0.850	0.533	0.788	Significant
	Rio 2016		0.962	0.885	0.132	0.688	0.063	0.579	0.381	0.315	
	London 2016		0.962	0.317	0.618	0.094	0.353	0.348	0.803	0.851	
Female	Tokyo 2020	8	0.265	0.729	0.835	0.976	0.420	0.919	0.585	0.705	Significant
	Rio 2016		0.325	0.054	0.349	0.228	0.838	0.449	0.764	0.956	
	London 2016		0.468	0.963	0.062	0.571	0.789	0.341	0.308	0.158	

[1] https://www.worldaquatic.org and https://www.swimswam.com

Table 3. Description of average result test on split time

Sex	Olympic	df	M ± SD							
			ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8
Male	Tokyo 2020	8	26.06 ± 0.54	28.17 ± 0.16	28.43 ± 0.12	28.63 ± 0.23	28.51 ± 0.33	28.65 ± 0.12	28.37 ± 0.20	27.48 ± 0.33
	Rio 2016		26.03 ± 0.27	28.10 ± 0.16	28.53 ± 0.17	28.65 ± 0.23	28.60 ± 0.47	28.60 ± 0.34	28.28 ± 0.78	27.41 ± 0.99
	London 2012		26.08 ± 0.33	28.23 ± 0.33	28.58 ± 0.15	28.84 ± 0.37	28.50 ± 0.36	28.69 ± 0.40	28.40 ± 0.75	27.68 ± 0.86
ANOVA			0.971	0.632	0.145	0.324	0.842	0.845	0.919	0.157
Female	Tokyo 2020	8	28.38 ± 0.51	30.35 ± 0.44	30.52 ± 0.47	30.79 ± 0.47	30.72 ± 0.52	30.94 ± 0.60	30.82 ± 0.80	30.12 ± 0.99
	Rio 2016		28.50 ± 0.41	30.47 ± 0.49	30.67 ± 0.47	30.98 ± 0.42	30.81 ± 0.51	30.95 ± 0.44	30.78 ± 0.61	29.89 ± 0.57
	London 2012		28.27 ± 0.33	30.43 ± 0.25	30.87 ± 0.22	31.09 ± 0.20	30.94 ± 0.40	31.22 ± 0.33	31.01 ± 0.44	30.28 ± 0.65
ANOVA			0.567	0.837	0.255	0.311	0.648	0.415	0.748	0.608

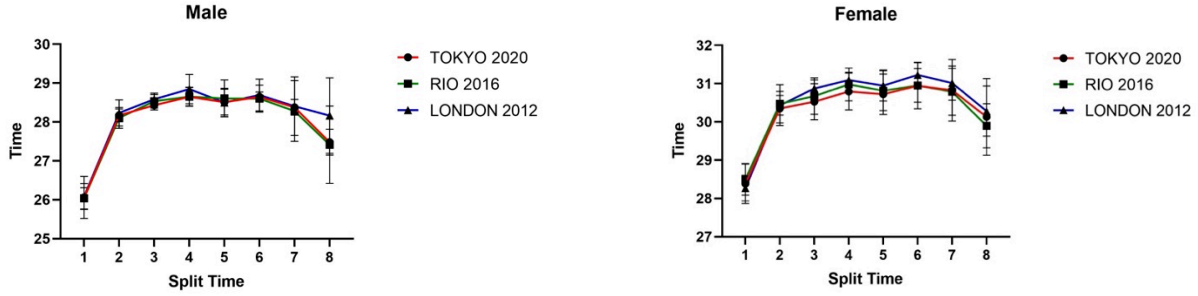

Fig. 1. Graph of the average male and female athletes for each 50-meter lap time

Table 3 above shows the results of the One-Way ANOVA test and the average test results for male and female athletes in the 400-meter freestyle during the 3 Olympic Games. It can be seen that all the results show that both male and female athletes did not experience changes in time during the 3 Olympic Games with a value of > 0.05.

Fig. 1 shows that there are differences in strategies among male athletes ahead of the Tokyo 2020, Rio 2016 and London 2012 Olympics. At the 2012 London Olympics, on average swimmers increased their speed at ST1, at ST2 to ST8 swimmers decreased and held their speed. Meanwhile, at the Tokyo 2021 and Rio 2016 Olympics, on average, swimmers increased their speed at ST1, at ST2 swimmers slowed down and held their speed until ST7, at ST8 swimmers increased their speed again. Female athletes experienced the use of the same strategy as male athletes by using time acceleration at ST1 and ST8 at the 2016 Rio Olympics only. This reduction in speed can be a strategy chosen by swimmers to avoid fatigue in the middle of the ST. Researchers also observed that by using this strategy swimmers could increase their speed in the final ST. This study also found a difference in the average time at ST8. This can be influenced by increasing stroke frequency and stroke length in swimmers. This is also in accordance with research (Barbosa et al. 2008). States that the greater the stroke rate, the faster the swimmer.

Table 4 above shows the average results of swimming times for male and female athletes in the 3 Olympic Games. Can be seen in male athletes, the acceleration in the 100-lap occurred at the 2016 Rio Olympics with a time of 54.14, the 200-lap occurred at Tokoyo 2020 with a time of 57.08, the men's 300 lap occurred at Tokyo 2020 with a time of 57.13, and in the 400 lap it occurred in Rio 2016 with a time of 55.71. While for female athletes the first lap acceleration occurred at the 2012 London Olympics with a time of 58.70, in the 200 lap it occurred at Tokyo 2020 with a time of 61.32, in the 300 lap it occurred at Tokyo 2020 with a time of 61.66, and in the last lap there was an acceleration in Rio 2016 with a time of 60.68.

Table 4. Description of the average swimming time result for each 100-meters

Sex	Olympic	M ± SD			
		100	200	300	400
Male	Tokyo 2020	54.23 ± 0.63	57.08 ± 0.34	57.13 ± 0.43	55.83 ± 0.40
	Rio 2016	54.14 ± 0.32	57.20 ± 0.26	57.36 ± 0.92	55.71 ± 1.71
	London 2012	54.32 ± 0.61	57.43 ± 0.51	57.19 ± 0.69	56.57 ± 1.66
Female	Tokyo 2020	58.73 ± 0.90	61.32 ± 0.93	61.66 ± 1.07	60.95 ± 1.78
	Rio 2016	58.97 ± 0.88	61.65 ± 0.86	61.77 ± 0.92	60.68 ± 1.06
	London 2012	58.70 ± 0.55	61.96 ± 0.38	62.17 ± 0.72	61.29 ± 1.00

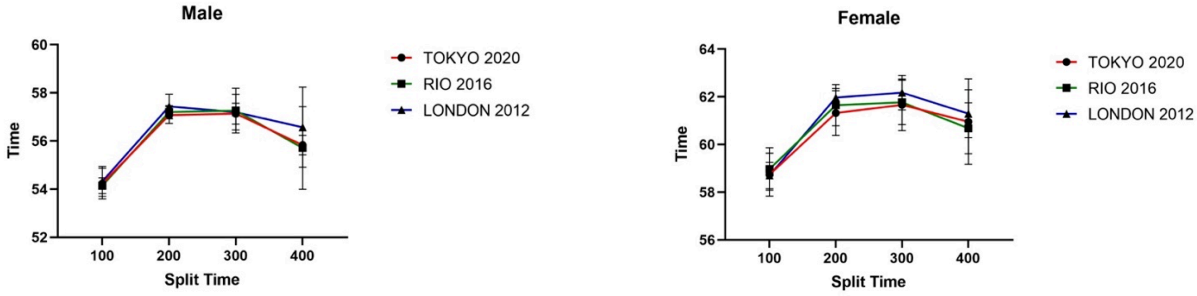

Fig. 2. Graph of the average male and female athletes for each 100-meter lap time

Fig. 2 above shows the average results in each 100-meter lap for male and female athletes. Male athletes experienced time acceleration at the Tokyo 2020 and Rio 2016 Olympics, while at London 2012 they did not experience time acceleration. Meanwhile, female athletes did not experience time acceleration during the 3 Olympic Games.

Table 5. Normality test result on RT and FT during 3 Olympic Games for male and female athletes

Sex	Olympic	Shapirow-Wilk		Information
		RT	FT	
Male	Tokyo 2020	0.806	0.056	Significant
	Rio 2016	0.564	0.128	
	London 2012	0.921	0.402	
Female	Tokyo 2020	0.482	0.494	Significant
	Rio 2016	0.200	0.394	
	London 2012	0.600	0.244	

Table 5 shows the results of the normality test carried out on the RT and FT variables for male and female athletes. All results show a normal distribution with values above 0.05 so that a difference test can be carried out.

Table 6. Average result and one way ANOVA difference test RT and FT

Sex	Olympic	RT	ANOVA	FT	ANOVA
		M ± SD		M ± SD	
Male	Tokyo 2020	0.70 ± 0.03	0.746	224 ± 0.70	0.461
	Rio 2016	0.71 ± 0.04		224 ± 2.25	
	London 2012	0.71 ± 0.02		225 ± 3.16	
Female	Tokyo 2020	0.72 ± 0.04	0.854	242 ± 4.17	<.001*
	Rio 2016	0.72 ± 0.03		252 ± 3.46	
	London 2012	0.73 ± 0.03		254 ± 1.92	

Table 6 shows the One-Way ANOVA test on the RT and FT variables, In the RT table, male athletes show no difference with a value of 0.746 for the FT variable, there is also no difference with a value of 0.461. Interestingly, in female athletes, there is a significant difference in the FT value with a value of < .001, but in RT there is no change in time acceleration with a value of 0.854.

Furthermore, the table explains the effect of RT on ST1 using a linear regression test. Based on the results of the analysis above, male athletes have an influence of 0.381 (14%) with a value of 0.001, and for female athletes, RT has a slight influence on ST1 with 0.066 (4%) with a value 0.342 in the 400-meter freestyle.

Table 7. Linear regression test on the influence of the RT to first ST

Sex	Variable	R Square	Sig.
Male	RT vs ST1	0.381	0.001
Female		0.066	0.342

Discussion

The aim of this research is to provide standards in strategies for developing swimming sports training programs, especially in the 400-meter freestyle. This analysis was carried out based on two categories ST, RT and FT for male and female swimmers who made it to the final round at the Olympics between 2012 and 2020.

The main finding in this research is that there are different strategies for each of the 3 Olympics held. At the 2012 London Olympics, the average swimmer only accelerated at ST1, while in the next ST until the end of the lap, both male and female athletes used constant speed. In contrast to the Tokyo 2020 and Rio 2016 Olympics, at ST1 the swimmers accelerated their speed, then at ST2 to ST7 the swimmers reduced their speed and used a constant rhythm and did not change their speed. Then in the last lap the swimmer relatively increases his speed. The strategy used by the average swimmer at the Tokyo 2020 and London 2016 Olympics uses a parabolic strategy, characterized by speeding up the swim at the start, followed by decreasing speed in the middle, and increasing speed in the last 50 meters (Mauger et al., 2012; Mytton et al., 2015; Oliveira et al., 2019). By reducing speed in the middle of this lap, we hope this will save energy for athletes until the last distance before the finish. Not only that, an increase in the number of strokes can cause an increase in swimming speed (Simbaña-Escobar, Hellard, & Seifert, 2020). Thus, elite swimmers can implement strategic settings in decreasing the total number of strokes or increasing the total number of strokes to minimize the decrease in speed in the middle of the race (Hellard et al., 2008). Elite athletes can minimize the decrease in speed very well in remembering every pull they do (Skorski & Abbiss, 2017). To achieve these abilities they must have experience and excellent training (Micklewright et al., 2010; Skorski et al., 2014). So the ability possessed by swimmers can utilize their own energy effectively and

at the same time can reduce fatigue in the initial phase (Puce et al. 2023).

ST1 times in all Olympics in this study, both male and female athletes produced faster times due to the large amount of energy the athletes had as well as the additional jumps and glides, this resulted in much faster times than the next ST (Mazzilli, 2019). This research found another thing that RT can have an influence of 14% (0.381) on the first ST. So this research is in accordance with previous research stating that when a swimmer leaves the starting block, speeding up the RT can provide an advantage to the swimmer, although this may decrease as the distance of the race increases (Born et al., 2024). By speeding up the jump from the starting block in the first ST, the speed of time will be much faster than in the next ST. Elite swimming at the start is related to the lower limb strength generated at the start (Carvalho et al., 2023) and in the water phase (Peterson Silveira et al., 2018). So that in the first 50 meters there is an acceleration of time, this is also the same as several other studies which state that optimal RT will have an impact on the swimmer's first ST (da Silva 2019). However, this has not had a high enough influence on female athlete's with an influence level of 4% (0.066). However, in contrast to the results of different RT and FT tests at each Olympics, this study found that the RT and FT 400-meter freestyle did not change over time during the 3rd Olympics. These differences indicate that each coach and athlete has adapted a unique strategy to improve their performance when starting swimming competitions. so that increases in ST, RT and FT are also related to the final results of the swimming athlete's performance. When jumping, swimmers can reach their maximum speed, so that swimmers can reach the 15-meter limit in a faster time (Morais, 2023; Thng et al., 2020), this is due to the lower drag force when underwater compared to when on the surface (Tor, Pease, & Ball, 2015).

Other results in this study found that the RT and FT 400-meter freestyle did not experience changes in time for male athletes during the 3 Olympics. However, this is different from female athletes, where there is a difference in final acceleration during the 3 Olympic Games. This difference in time acceleration indicates that each coach and athlete has adapted a better strategy to improve their performance when starting swimming competitions. So that increases in ST, RT and FT are also related to the final results of the swimming athlete's performance.

Conclusions

This study found a very interesting new thing in the strategy used by swimmers in the 400 meters, the first and last splits are the most important part of the strategy for achieving the best time in the 400 meters freestyle. These two indicators look so simple, but in the process of realizing the first and last split time athletes must have very optimal performance. Besides that the split time in each lap must be conditioned by being measured by each athlete. Athletes and coaches must be very careful in carrying out swimming exercises, especially in tapering exercises, the achievement of time must be ensured precisely and measurably so as to produce the best time in the 400 meters freestyle. Tapering exercises will provide experience for athletes in managing the energy expended while swimming. Future research will be better by adding other indicators such as calculating stroke rate, physiology, and biomechanics of movement.

Conflict of Interest

The author states that there are no conflicts of interest regarding the publication of this manuscript.

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Олімпійські ігри: Удосконалення стратегії змагальної діяльності щодо розвитку майстерності техніки елітних плавців на дистанції 400 метрів вільним стилем

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

Реферат. Стаття: 8 с., 7 табл., 2 рис., 36 джерела.

Історія питання. На чемпіонатах з плавання визначення стратегії вважається головним чинником, особливо у змаганнях на середні та довгі дистанції. Впровадження змін до стратегії може опосередковано вплинути на кінцеві результати.

Мета дослідження. Метою дослідження було з'ясувати, чи існують достовірні відмінності у наступних показниках: час реакції (ЧР), фінальний час (ФЧ) та стратегії для кожного періоду проміжного часу (ПЧ) у змаганнях з плавання на дистанції 400 метрів вільним стилем серед чоловіків та жінок на Олімпійських іграх в Токіо (2021), Ріо-де-Жанейро (2016) та Лондоні (2012).

Матеріали та методи. У дослідженні застосовано кількісні методи з обсягом вибірки 48 спортсменів. Джерело інформації включало використання вторинних даних. Описова статистика представлена у вигляді середніх значень і стандартних відхилень. З метою перевірки нормальності даних використовувався критерій Шапіро-Вілка. За допомогою однофакторного дисперсійного аналізу (ANOVA) проведено порівняльний аналіз даних ЧР, ФЧ та ПЧ. Для визначення впливу ЧР на показник першого періоду ПЧ застосовано тест лінійної регресії.

Результати. Результати проведеного дослідження вказують на наявність відмінностей у показниках ЧР спортсменів-чоловіків впродовж 3-х Олімпійських ігор. Дослідження також виявило зміни в показниках середньої швидкості. Загалом плавці збільшили свою швидкість на рівнях ПЧ1 та ПЧ8. Такі дані спостерігалися на Олімпійських іграх у Токіо-2021 та Ріо-де-Жанейро-2016, тоді як на Олімпійських іграх у Лондоні-2012 плавці збільшили швидкість лише на рівні ПЧ1. Крім того, результати продемонстрували, що ЧР мав вплив 0,381 (14 %) на показник першого періоду ПЧ у спортсменів-чоловіків, тоді як у спортсменок це значення було менш вираженим — 0,066 (4 %).

Висновки. У цьому дослідженні встановлено, що показники ПЧ1 і ПЧ8 є найважливішими компонентами у плаванні на 400 метрів вільним стилем як серед спортсменів чоловічої, так і жіночої статі. Тренери та спортсмени мають з особливою ретельністю підходити до проведення спеціальних тренувань на етапі тейперінгу (англ. tapering — це фаза підготовки, що передує змаганням, під час якої проводять зниження тренувального навантаження), щоб забезпечити спортсменам потрібний час для досягнення найкращого результату.

Ключові слова: стратегія плавання, результативність, аналіз, олімпіада.

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Original Scientific Article

Analysing Differences in Attack Indicators in Men's First Division Volleyball According to The Positional Status of Teams

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Abstract

Background. Attack efficiency in the game of volleyball is of paramount importance in winning competitions.

Objectives. The study aimed to analyse the differences in attack efficiency between teams of varying value levels, according to their position in the ranking.

Materials and methods. All 12 teams participating in the men's national first league championship were analysed using the Data Volley software. The attack parameters were compared between teams in the first half of the ranking vs teams in the second half. Another comparison was performed for 3 value levels of the top teams (top, middle, and low).

Results. The Mann-Whitney U test (used to assess the differences between teams in the first half vs. teams in the second half of the ranking) indicates Z values associated with statistically significant thresholds ($p < 0.05$) for most of the attack indicators, except Blocked but recovered% ($p > 0.05$). The situation is similar also for the Kruskal-Wallis test, where χ^2 values indicate significant differences between the three levels of the teams for most of the parameters, except Blocked but recovered%.

Conclusions. The findings reveal the higher values of attack efficiency and its parameters for the teams placed in the top positions of the ranking. The teams in the first half of the ranking have better percentage values on the executions associated with Winning% and Positive%. The attacking players of these teams also demonstrate lower percentage scores on the executions associated with Error%, Blocked attack% and Poor%, thus committing fewer mistakes. The situation is similar when comparing the top vs low and middle vs low pairs, where only for Blocked but recovered% no significant differences have been identified. These results support the need to focus on making the volley attack more efficient as a decisive factor in competitive success.

Keywords: attack efficiency, errors, value level, differences, volley.

Introduction

Investigations on men's youth (high-level) national teams participating in the Volleyball World Championships have identified the importance of strong, fast, and accurate attacks in achieving success. This process ensures overcoming aggressive defences. However, the execution of these attacks requires a high technical level and superior adaptability to the variable conditions of the volleyball game (Costa et al., 2010). The analysis of elite team matches (World Cup) identified 3 factors that increase attacking efficiency: Number of blockers, Attack tempo, and Attack type. Attack tempo 1 and Power attack ensure the highest chances of winning points (Castro et al., 2011). The positive results of the teams at the Volleyball World Championship indicate the importance of attack efficiency for winning sets. The points accumulated in attack were more when preceded by perfect dig execution (Monteiro et al., 2009).

Research on junior and senior men's and women's volleyball teams reports a similar level of knowledge of individual attack principles in volleyball. The level of experience and gender do not influence the correctness and speed of choosing attack solutions by computer simulation (Szade & Szade, 2005). Comparisons of game actions and attack efficiency between male and female teams in the Estonian volleyball championship indicate a higher efficiency of men. Male teams use more fast attack/tempo 1, but also a vigorous

spike more often than female teams (Stamm et al., 2016). The gender comparison for attack and serve efficiency (male vs female volleyball teams participating in the European Volleyball Golden League) shows differences. Males risk more on serve and have higher efficiency in attack compared to females. Male opposite players have superior involvement and efficiency in attack vs female opposite players (Lima et al., 2019). Another study analyses predictors of success for volleyball teams participating in the European Championship and shows gender differences. For females, the most important predictors are excellence and attack efficiency. However, for males, points accumulated from service winners and points obtained from kill blocks are more relevant (Přidal & Priklerová, 2018).

The attack analysis for the first Romanian men's volleyball league indicates the importance of short lift which precedes the most efficient attack. However, average lifting precedes most attacks. Zone 4, then zone 2 are the most required for attack execution in both variants (attack after reception and attack on dig) (Cojocaru & Cojocaru, 2018). The individual characteristics of volleyball players at the elite level can greatly vary at the top level. Different approaches to the phases of the game and exploring the abilities of one's team are important, avoiding the application of standardized patterns. For the offensive phase, variables with high levels of centrality are: Attack Zone 4, Attack Tempo 2, Power Attack, Attack Effect Continuity etc. (Rocha et al., 2023). For teams in the attacking phase in volleyball, reducing the opponents' possibilities of anticipating actions requires having varied strategies and ways of approaching the attack (Marcelino et al., 2014). The duration of rallies influences the teams' chances of scoring points. For short rallies (8-10 s), if the rally is not completed after the first attack, then the team that executed the serve can perform the attack and get the point. For longer rallies (more than 10 s), both teams have balanced chances of success (Sánchez-Moreno et al., 2017). Regarding the technique of hitting the ball in a volleyball attack, there are studies that analyse the evolution of this variant at the Olympic Games. It was found that the most commonly used procedures are Circular and Snap arm swing, with effects in reducing injuries and increasing ball speed (Giatsis & Tilp, 2022).

Improving the attack success for high-level Cypriot volleyball players is conditioned by the optimization of vertical jump heights and attack technique. It was found that attack efficiency is better with age increase, but higher spike speeds (over 90 km/h) reduce efficiency, according to Challoumas and Artemiou (2018). For volleyball players, significant relationships were found between the value of jumps during attack actions and the final winner/loser outcome. Increasing the value of jumping ensures the efficiency of offensive actions, according to Joksimovic et al., (2024), Pawlik and Mroczek (2023). Other studies explain the association between the physical performance of elite volleyball players and game action performance during a competitive season (García-de-Alcaraz et al., 2023). Executing an attack from the second line increases point winning opportunities. This variant requires an improvement in the explosive arm strength for the attack and the movement speed required for execution from zones 1 and 6 (Cojocaru & Cojocaru, 2019).

The use of the Attack-Block-Court Defence algorithm allows coaches to perform a personalised design of attack and defence systems, based on the relationship between attacker and blocker (Cantú-González et al., 2022). The use of algorithms for statistical analysis of technical and tactical indicators of competitive activity in volleyball is very useful for modifying the training process. Game positions, performance indicators, individual and group actions for attack and defence, critical moments, quantitative indicators, etc. are interpreted (Iermakov et al., 2023; Oliinyk et al., 2021; Szabo et al., 2019). The use of Data Volley software facilitates the analysis of technical-tactical performance in volleyball games. It ensures an understanding of the relationship between the reception zone and attack quality (Fatahi et al., 2022). Data Volley Software is the most widely used version in volleyball worldwide. Its use allows the understanding of the dynamics and evolution of the volleyball game, identifying the factors that influence the performance of the analysed teams (Silva et al., 2016).

Research on men's volleyball teams in Greece has determined 5 skills that make the difference between top and lower level teams: serve, pass, block, attack after passing, and attack after defence. The ratio of successful vs unsuccessful executions is an indicator of skill performance (Drikos & Tsoukos, 2018). The quality of the opponents/quality of the opposition directly influences the choice and execution of technical-tactical actions in elite volleyball. For matches with value-balanced opponents, the risks taken are lower. Facing weaker opponents/unbalanced opponents also increases the chances of choosing riskier solutions (Marcelino et al., 2011).

Most of the analysed references indicate the importance of attack in men's volleyball as a decisive element in achieving competitive success. Our research aims to analyse the differences in attack efficiency (E%) between teams of different value levels, according to their position in the ranking.

H1: We estimate that we will obtain significant differences in attack efficiency (E%) and its associated variables between men's first league teams (first half of the ranking vs second half of the ranking).

H2: We estimate that we will obtain significant differences in attack efficiency (E%) and its associated variables between men's first league teams (categorized for top, middle, and low levels).

Materials and Methods

Study Participants

All players in the Romanian men's first division volleyball championship (86 participants) were included in the study. They have positions and attributes related to the attacking phase (outside hitter, opposite hitter, and middle blocker). The requirements to ensure the confidentiality of the data obtained from the participants, according to the Declaration of Helsinki, were respected (Sandu, 2012; "World Medical Association Declaration of Helsinki", 2013). The consent of the Ethics Committee of the Faculty of Physical Education and Sports (242/10.07.2024) was obtained for the publication of the data.

Study Organization

The Data Volley software was used by each of the 12 teams to record the specific parameters of the attack phase, during three stages of the championship (2018). For each player, the

Table 1. Attack execution variants and their encoding

Scale	Code	The meaning	Description
1	=	Error	(Out, net ball, invasion)
2	/	Blocked attack	(Point goes to the opponent)
3	-	Poor	(Easily dug by the opponent who can try and play the ball again)
4	!	Blocked but recovered	(Blocked but recovered by the home team)
5	+	Positive	(Opponent defended with difficulty and the home team can try and play the ball again)
6	#	Winning	(Direct point)

attack efficiency (E%) was calculated and the attack executions were categorized into 6 qualitative levels, according to Table 1, which summarizes the codes and their meaning, according to the Data Volley book (Data Project, 2024).

All data was transferred to the Human Performance Research Centre of the Faculty of Physical Education and Sports of Galati. The data was centralised and grouped according to the value level for the players of the teams in the first half (6 teams) and second half (6 teams) of the ranking. For a more precise analysis, it was also grouped into 3 value levels (top/teams 1-4, middle/teams 5-8, low/teams 9-12).

Statistical Analysis

SPSS Software was used for data transfer and statistical calculation (Statistical Package for the Social Sciences/IBM (Vers. 24 Chicago, IL, USA). Descriptive statistics were applied to obtain mean values and their associated indicators. The Shapiro Wilk test was used to assess the normality of data distribution. The nonparametric Kruskal-Wallis and Mann-Whitney U tests were applied to identify differences between groups of established value levels. The confidence interval was set at 95 %.

Results

Table 2 summarizes the data for attack across the entire lot, with mean values, lower/upper limits, and the sum of executions. The minimum negative value for Attack Efficiency is found for a player in the low part of the ranking. It can be observed that of the total executions, most correspond to the winning variant and the fewest are recorded for the blocked but recovered variant. Regarding the percentages of the 6 execution steps, the highest average values are for winning and poor, and the lowest for blocked but recovered and blocked attacks.

The comparison of the percentages for attack efficiency and the framing for the six levels of execution between the averages of the first half and second half teams are shown in Figure 1. We identified higher values for E%, winning and positive variants in the first half group, while the values for poor executions (error, blocked attack, and poor) are higher for the second half group. However, for the blocked but recovered execution variants, we identified similar percentage values for the two batches.

Table 3 summarizes the significance of the differences between the first half and second half groups. Significant differences ($p < 0.05$) in favour of the first half lot are obtained for E%, Positive% and Winning%, and in favour of the second half lot for Error%, Blocked attack% and Poor%. The only insignificant difference is for Blocked but recovered%, where the Z value is associated with a $p > 0.05$.

The mean values for the independent variables studied, resulting from dividing the sample into 3 performance levels, are presented in Figure 2. The top group has higher scores for E%, Winning% and Positive%, followed by the middle group. For less successful or failed executions (Error%, Blocked attack% and Poor%) higher values are reported for the low

Table 2. Average results of the independent variables for the whole group (n = 86)

Dependent variables	Minimum	Maximum	Sum	Mean	Std. Error	Std. Deviation
Attack Efficiency (E%)	-22.00	57.00	2106.00	24.4884	1.43169	13.27691
Total attack executions	8.00	145.00	3515.00	40.8721	2.97168	27.55819
(=) Error executions	1.00	15.00	355.00	4.1279	.37163	3.44638
(=) Error%	2.00	22.00	866.00	10.0698	.42904	3.97874
(/) Blocked attack executions	1.00	18.00	330.00	3.8372	.37641	3.49070
(/) Blocked attack%	3.00	32.00	768.00	8.9302	.47705	4.42397
(-) Poor executions	1.00	24.00	557.00	6.48	.585	5.427
(-) Poor%	4.00	34.00	1285.00	14.9419	.67135	6.22586
(!) Blocked but recovered executions	1.00	9.00	277.00	3.2209	.21781	2.01991
(!) Blocked but recovered%	1.00	21.00	788.00	9.1628	.50003	4.63709
(+) Positive executions	1.00	25.00	467.00	5.4302	.45974	4.26350
(+) Positive%	4.00	30.00	1149.00	13.3605	.49895	4.62706
(#) Winning executions	3.00	71.00	1529.00	17.8605	1.36431	12.65205
(#) Winning%	17.00	67.00	3756.00	43.6744	.98892	9.17085

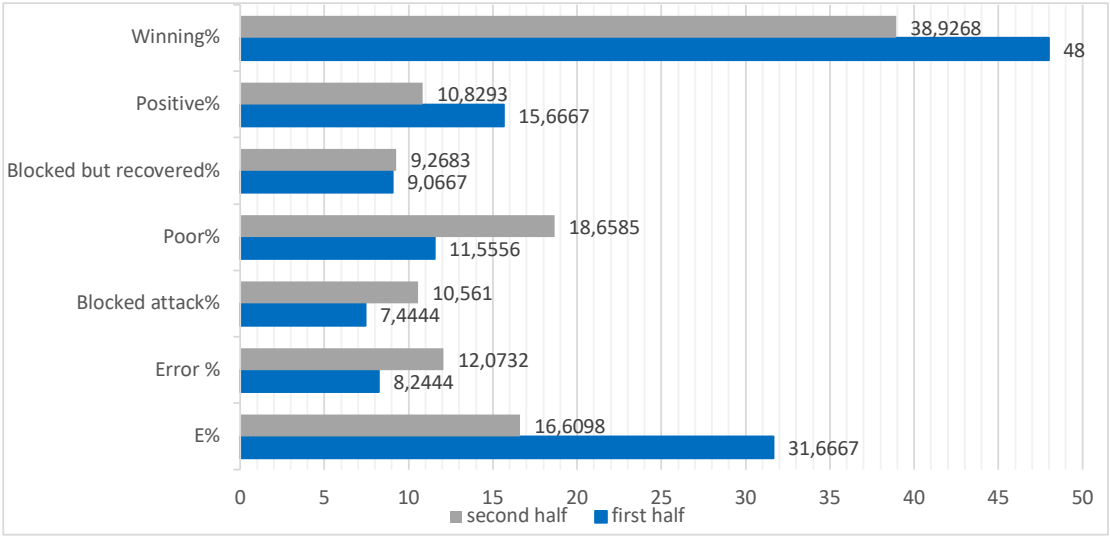

Fig. 1. Average attack efficiency values and percentages for the 6 execution variants at the first half and second half of the championship level

Table 3. Results of the Mann-Whitney U test for pairwise comparison of results (first half vs. second half of the ranking)

Variables	Level	n	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Sig. (2 tailed)
E%	first half	45	57.83	2602.50	277.500	-5.580	.000
	second half	41	27.77	1138.50			
Error%	first half	45	32.28	1452.50	417.500	-4.381	.000
	second half	41	55.82	2288.50			
Blocked attack%	first half	45	35.10	1579.50	544.500	-3.282	.001
	second half	41	52.72	2161.50			
Poor%	first half	45	29.57	1330.50	295.500	-5.433	.000
	second half	41	58.79	2410.50			
Blocked but recovered%	first half	45	42.27	1902.00	867.000	-.482	.630
	second half	41	44.85	1839.00			
Positive%	first half	45	56.74	2553.50	326.500	-5.172	.000
	second half	41	28.96	1187.50			
Winning%	first half	45	56.82	2557.00	323.000	-5.190	.000
	second half	41	28.88	1184.00			

batch, followed by the middle batch. Only for Blocked but recovered%, we identified close values between the low and middle batches.

The results of the Kruskal-Wallis test for the significance of the differences between the 3 value levels are summarized in Table 4. The χ^2 values indicate the existence of significant differences between the medians of the dependent variables, except Blocked but recovered%.

The significance of the differences between the top vs middle groups is presented in Table 5 Mann-Whitney U test. The statistical superiority of the top group is confirmed for most variables (Z values are associated with a $p < 0.05$). The exceptions are Blocked attack% and Blocked but recovered% ($p > 0.05$).

The differences between middle vs low and top vs low performance are summarized in Tables 6 and 7. In both situations, we recorded significant differences for most of the analysed variables, which indicates lower percentages of success of the low group for Efficiency, Positive, and Winning, plus higher percentages of the same group for wrong or inefficient executions of the attack (Error, Blocked attack, and Poor variants).

Table 4. Values of the Kruskal-Wallis test associated with the dependent variables for the 3 ranking levels (top, middle, and low)

Variables	χ^2	df	Sig.
E%	41.769	2	.000
Error%	22.479	2	.000
Blocked attack%	15.093	2	.001
Poor%	29.337	2	.000
Blocked but recovered%	1.195	2	.550
Positive%	34.933	2	.000
Winning%	34.176	2	.000

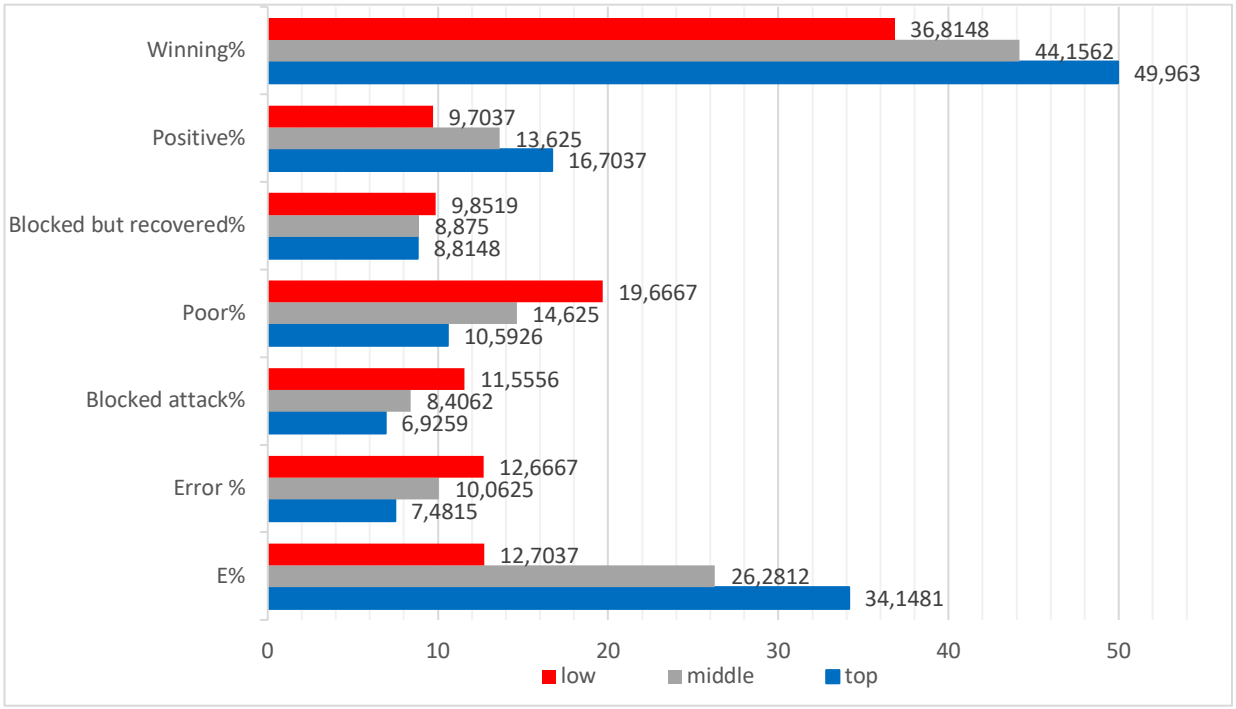

Fig. 2. Average attack efficiency values and percentages for the 6 execution variants at the top, middle, and low levels of the championship ranking

Table 5. Results of the Mann-Whitney U test for pairwise comparison of results (top vs middle of the ranking)

Variables	Level	n	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Sig. (2 tailed)
E%	top	27	37.30	1007.00	235.000	-3.000	.003
	middle	32	23.84	763.00			
Error%	top	27	23.61	637.50	259.500	-2.636	.008
	middle	32	35.39	1132.50			
Blocked attack%	top	27	25.74	695.00	317.000	-1.764	.078
	middle	32	33.59	1075.00			
Poor%	top	27	22.87	617.50	239.500	-2.938	.003
	middle	32	36.02	1152.50			
Blocked but recovered%	top	27	29.80	804.50	426.500	-.084	.933
	middle	32	30.17	965.50			
Positive%	top	27	36.78	993.00	249.000	-2.797	.005
	middle	32	24.28	777.00			
Winning%	top	27	37.17	1003.50	238.500	-2.951	.003
	middle	32	23.95	766.50			

Discussion

Many specialised studies confirm the importance of attack in volleyball, as a decisive action in achieving victory. Attack is the main factor in scoring points for top teams participating in the European Championship. The number of errors at this level is lower. However, for matches with 5 sets or long sets (more than 25 points) an increasingly important role is played by the points obtained by blocking (Rodriguez-Ruiz et al., 2011). The factors that determine performance in volleyball in 4 European leagues (Germany, Italy, Poland, and Turkey) are diversified. Winning matches are influenced by the following parameters: the number of players earning points in attack, team value/team category, service points, blocked balls, reception errors, etc. (Peña & Casals, 2016). For Spanish volleyball players (U19), the top positions in the final ranking are influenced by the quality of the attack and other phases of the game, except serve

Table 6. Results of the Mann-Whitney U test for the pairwise comparison of results (middle vs low of the ranking)

Variables	Level	n	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Sig. (2 tailed)
E%	middle	32	40.09	1283.00	109.000	-4.920	.000
	low	27	18.04	487.00			
Error%	middle	32	24.52	784.50	256.500	-2.681	.007
	low	27	36.50	985.50			
Blocked attack%	middle	32	25.00	800.00	272.000	-2.443	.015
	low	27	35.93	970.00			
Poor%	middle	32	23.23	743.50	215.500	-3.305	.001
	low	27	38.02	1026.50			
Blocked but recovered%	middle	32	28.30	905.50	377.500	-.832	.406
	low	27	32.02	864.50			
Positive%	middle	32	38.52	1232.50	159.500	-4.167	.000
	low	27	19.91	537.50			
Winning%	middle	32	38.50	1232.00	160.000	-4.147	.000
	low	27	19.93	538.00			

Table 7. Results of the Mann-Whitney U test for the pairwise comparison of results (top vs low of the ranking)

Variables	Level	n	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Sig. (2 tailed)
E%	top	27	39.48	1066.00	41.000	-5.602	.000
	low	27	15.52	419.00			
Error%	top	27	17.89	483.00	105.000	-4.505	.000
	low	27	37.11	1002.00			
Blocked attack%	top	27	19.52	527.00	149.000	-3.741	.000
	low	27	35.48	958.00			
Poor%	top	27	16.72	451.50	73.500	-5.045	.000
	low	27	38.28	1033.50			
Blocked but recovered%	top	27	25.22	681.00	303.000	-1.069	.285
	low	27	29.78	804.00			
Positive%	top	27	38.89	1050.00	57.000	-5.344	.000
	low	27	16.11	435.00			
Winning%	top	27	38.57	1041.50	65.500	-5.180	.000
	low	27	16.43	443.50			

(Conejero et al., 2017). Our research supports these views, highlighting a higher quality of attack for teams at the top of the ranking.

The Brazilian Men's Super League study highlighted factors that condition the efficiency of attack in zone 4. These refer to the quality of receptions, power of diagonal attack and fast attack tempo (G. C. Costa et al., 2017). For men's beach volleyball competitions, differences are found between the winning and losing teams for several variables. Winners accumulate more points from counterattacks, while opponents commit more attack errors (Medeiros et al., 2017). Investigations at the level of top men's teams in European volleyball indicate the major role of attacking and blocking, which make the difference between winning and losing teams. Also, reducing the number of errors is a goal pursued in training and competitions (Häyrinen et al., 2004). At the level of the Spanish men's volleyball super league, factors that can predict the chances of winning are analysed. Placing at the top of the standings, the number of attacks blocked by the opponents and reception errors are indicators of winning or losing a match. Improving performance implies increasing the attack efficiency and decreasing unforced attacks related to errors (Peña et al., 2013). Regarding errors committed in attack execution, our study identified higher Error%, Blocked attack% and Poor% variances for teams placed in the lower part of the ranking.

Attack remains the main element ensuring success for men's volleyball teams (elite level) participating in world tournaments. Most points are earned based on attack, followed by block and serve (Bozhkova, 2013). For European

men's volleyball/elite teams, higher counter-attack phase/spike efficiency scores were determined for the winning teams compared to the losing teams. However, no differences were also reported for attack phase spike, according to (Klaričić et al., 2018). Counter-attack efficiency, medium and slow attack-tempo efficiency are predictors that differentiate top-level teams from those placed in the lower echelon (Stutzig et al., 2015). Our investigation identified higher values of attack effectiveness by value level in three categories: 36.81 % for low teams, 44.15 % for middle, and 49.96 % for top teams.

A 4-season study of the Italian men's volleyball championship studied the relationship between pass quality and first attack. Defeats are predicted by Error Attack over 10 % and Attack points under 51 %. Values less than 7 % for blocked attack and Attack points under 51 %. Values less than 7 % for blocked attacks and Attack points over 58 % indicate increased chances of victory (Lobietti et al., 2009). In our research, we obtained Error% values of 12.56 % for low teams, 10.06 % for middle, and 7.48 % for top teams. Regarding Blocked attack%, our teams have values of 6.92 % for top, 8.40 % for middle, and 11.56% for low, which is in confirmation with the data of the previously analysed studies.

Strong and fast attacks are crucial in the volleyball game for the elite male youth teams participating in the World Championship. Powerful attacks facilitate getting points in transition and side-out phases, according to (G. C. Costa et al., 2011). The factors that ensure victory for male teams of 3 value levels, participating in a world tournament (upper, middle, and lower) emphasize attack efficiency as the main argument. For elite teams, ace serves are a decisive factor and defence errors are decisive for matches between teams of different value levels (Drikos et al., 2022). The value level of opponents (QO/Quality of opposition) in volleyball influences the style of play. Value-balanced matches (top vs top or weak vs weak) lead to more changes in the playing style than those between opponents of different values (top vs weak). This aspect is particularly found in the first age groups (García-de-Alcaraz & Marcelino, 2017). Analysis of game phases for teams of young Spanish volleyball players revealed differences in game actions, acting as feedback for performance improvement. For serve, defence, setting, and spike/attack these differences are significant between winning and losing teams (Claver Rabaz et al., 2013). Investigations on volleyball teams participating in the World Cup determined differences in attack and serve efficiency between top and lower level teams. Higher level teams mobilize better and have better execution/rallies for final sets. Lower level teams have a similar performance during the sets/full match, according to R. O. Marcelino et al. (2012). Our investigation identified higher values of the first half teams than the second half teams for E% (31.66 % vs 16.60 %), Winning% executions (48 % vs 38.92 %), and Positive% executions (15.66 % vs 10.82 %).

For our study, the two working hypotheses are confirmed, with significant differences for E% and most Attack variables between teams of different value levels. The obtained results are important indicators for coaches, who can identify the weaknesses of their teams and find solutions to improve attacks. The high volume of data resulting from the statistical analysis did not allow us to present all the results. The values and differences for the playing positions involved in the attack (outside hitter, opposite and middle blocker) will be presented in another scientific paper. Also, analysing the type of attack and investigating complex 1 and complex 2 are future research directions.

Conclusions

The results indicate the higher values of attack efficiency and its parameters for the teams placed in the higher positions of the ranking, which have valuable players with better results for the attack phase. The teams in the first half of the ranking have better percentage values on executions associated with Winning and Positive. The attack players of these teams also have lower percentage scores on executions associated with Error, Blocked attack, and Poor, so they make fewer mistakes. The situation is similar for the comparison of the top vs low and middle vs low pairs, where only for Blocked but recovered% we did not identify significant differences. For the top vs middle pair, we identified higher attack values for the first group, but no significant differences for Blocked attack% and Blocked but recovered%. These results support the need to focus on attack efficiency in volleyball as a decisive factor in competitive success.

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Conflict of Interest

The authors have no conflict of interest to declare.

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Аналіз відмінностей показників атакуючих дій у чоловічому волейболі першого дивізіону відповідно до позиційного статусу команд

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

Реферат. Стаття: 10 с., 7 табл., 2 рис., 47 джерел.

Історія питання. Ефективність атакуючих дій у волейболі має першочергове значення в контексті здобуття перемоги у змаганнях.

Мета дослідження. Метою дослідження було проаналізувати відмінності щодо ефективності ведення атакуючих дій між командами різного рівня значущості, згідно з їхньою позицією в рейтингу.

Матеріали та методи. Усі 12 команд, що беруть участь у національному чемпіонаті першої ліги серед чоловіків, проаналізовано за допомогою програмного забезпечення Data Volley. Здійснено порівняльний аналіз щодо параметрів атакуючих дій між командами з першої половини рейтингу та командами з другої половини рейтингу. Також проведено порівняльний аналіз 3 рівнів значущості провідних команд (високий, середній та низький).

Результати. U-критерій Манна-Уітні (застосовано для оцінки відмінностей між командами першої половини рейтингу та командами другої половини рейтингу) вказує на Z-значення, пов'язані зі статистично значущими порогами

($p < 0,05$) для більшості показників атакуючих дій, за винятком відсотка блокованих, але відбитих ударів ($p > 0,05$). Аналогічна ситуація спостерігається також за критерієм Краскела-Волліса, де значення χ^2 вказують на суттєві відмінності між трьома рівнями команд для більшості параметрів, за винятком відсотка блокованих, але відбитих ударів.

Висновки. Отримані дані свідчать про вищі показники ефективності виконання атаки та її параметрів для команд, що посідають провідні позиції в рейтингу. Команди з першої половини рейтингу мають кращі відсоткові показники виконання подач, пов'язаних з відсотком виграних та успішних подач. Атакуючі гравці зазначених команд також демонструють нижчі відсоткові показники виконання подач, пов'язаних з відсотком похибок, блокованих атак і невдалих дій, тобто допускаючи меншу кількість помилок. Аналогічна ситуація спостерігається й щодо порівняння показників пар команд за рівнем значущості: високий — низький та середній — низький, де лише для відсотка блокованих, але відбитих ударів не було виявлено жодних істотних відмінностей. Зазначені результати підтверджують необхідність зосередитися на підвищенні ефективності атакуючих дій щодо виконання удару зльоту як вирішального фактору успіху в змаганнях.

Ключові слова: ефективність атакуючих дій, похибки, рівень значущості, відмінності, удар зльоту.

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Original Scientific Article

Estimating the Effect of Contrast Exercises Using Conventional Deadlifts and Air Rower on Increasing Leg Muscle Strength and VO_2max in Rowing Athletes

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

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Abstract

Objectives. This study aimed to prove the effect of contrast training using conventional deadlifts and air rowers on the increase of leg muscle strength and VO_2max in rowing athletes.

Materials and methods. This study used a true-experimental method with a two-group pretest-posttest approach, involving a control group design. A total of 22 rowing athletes, aged 19-23 years, and recruited from the Surabaya City training centre, were involved in the study. The athletes received a contrast training intervention with a high intensity of 85-90 % 1RM, conducted thrice per week for a six-week period. Leg strength and back strength, leg power, and VO_2max were evaluated between pre- and post-intervention in each study group.

Results. The results showed that leg strength and back strength, leg power, and VO_2max were found to be significantly improved after performing a contrast exercise intervention compared to the control group ($p \leq 0.05$).

Conclusions. These findings suggest that contrast training combining conventional deadlifts and air rowers is an effective method of increasing leg muscle strength and power, as well as VO_2max in rowing athletes, so that it can provide benefits to enhance the explosive strength and aerobic endurance of these athletes.

Keywords: explosiveness, rowing athletes, aerobic endurance, contrast training.

Introduction

In rowing sports, efficient and explosive movements start from the push of the legs, which is the main source of power for moving the boat (Vieira et al., 2020). The leg muscles, especially the quadriceps, hamstrings, gluteus, and gastrocnemius, play a crucial role in generating initial strength during each cycle of rowing movements (Cardoso et al., 2024). Rowing athletes harness the strength of their leg muscles to provide a strong push, which is then followed by the contribution of the back and arm muscles (Chang et al., 2024). Rowing is a complex activity involving kinetic chains that start from the push of the legs and move through the upper body until reaching the pull of the paddle (Cady-McCrea et al., 2024). Therefore, leg muscle strength is essential in effectively transferring energy from the lower body to the upper body (Vieira et al., 2020).

Posture control and stability are indispensable for rowing athletes to maintain technical efficiency in each movement (Duchene et al., 2024). Strong leg muscles not only support force transfer but also contribute to postural stability, ultimately improving rowing technique as well as reducing errors that can affect performance (Chang et al., 2024). Additionally, in race situations, especially at the start and finish, rowing athletes need explosive power to provide maximum acceleration in a very short time (Cardoso et al., 2024). Leg muscle strength plays a key role in this critical phase, where rapid acceleration and explosive thrust can be the difference between victory and defeat (Chang et al., 2024).

In addition to the importance of explosiveness, stability and balance when rowing also depend on the strength of the leg muscles (Promsri et al., 2018; Alonso et al., 2011). If this force is insufficient, the distribution of the load during rowing becomes unbalanced, which increases the risk of injury, especially in the back, knees, and ankles (Zemková, 2022; Podgórski et al., 2020). Previous research has shown that optimal leg muscle strength is a predictor of success in rowing competitions (Thiele et al., 2020; Lawton et al., 2013; McNeely et al., 2005).

ТМФВ
ТОВ ОВС

To increase the strength of the leg muscles, several exercise methods can be used. One of them is contrast training, which is an exercise method that combines heavy weight training with explosive training in one session (Barra-Moura et al., 2024; Paulo Henrique Pauli et al., 2023). Deadlift is one of the most effective exercises in increasing posterior kinetic chain strength in athletes, including rowing athletes, because it involves many muscle groups, especially lower body muscles (Cholewa et al., 2019). Previous research has shown that high-load resistance training (≥ 85% of 1RM) is effective for improving explosive strength and performance (Hagerupsen et al., 2024; Cormie et al., 2010; Comfort et al., 2012; Øvretveit & Tøien, 2018).

In addition to deadlifts, the use of tools such as air rowers in contrast training programs can provide explosive exercises that mimic the specific movements of the paddles (Thiele et al., 2020). Air rowers help to train the leg and upper body muscles simultaneously, as well as improve cardiovascular capacity and explosiveness (Chang et al., 2024). The combination of deadlift as a weight exercise and air rower as an explosive exercise in a contrast training program is expected to increase leg muscle strength more effectively compared to conventional methods.

This study aims to prove the effect of contrast training that combines conventional deadlift training and air rowing training on increasing leg muscle strength in rowing athletes. Based on previous research that shows the effectiveness of weight and explosive training, this research is expected to make a significant contribution to the understanding of optimal training programs for rowing athletes.

Materials and Methods

Study Design

This study uses a true experimental method with two group pretest-posttest with a control group design. A total of 22 rowing athletes were recruited from the Surabaya City training center aged 19-23 years and divided into two study groups, namely the control group (CTR; n = 11), the contrast training group (CNT; n = 11). CTRs did not receive any training interventions, while CNT received 3x/week interventions for 6 weeks. All subjects voluntarily gave consent to participate by filling out and signing the consent given by the researcher and all procedures applied in this study have complied with the Helsinki World Medical Association Declaration on the ethical conduct of research involving human subjects.

Contrast Training Methods

This Contrast Training program focuses on increasing maximum power and explosive power, starting with the Conventional Deadlift at 85% 1RM load and Air Rower at 30% 1RM load. In weeks 3 and 4, the intensity increases with conventional deadlifts using 90% 1RM (3 sets, 3 reps, 15 seconds rest), while air rowers remain at 30% 1RM (3 sets, 5 reps, 3 minute rests). In weeks 5 and 6, the intensity increases further with conventional 90% 1RM deadlifts (3 sets, 3 reps), but the rest time is trimmed to 10 seconds, forcing the body to adapt to a faster transition between maximum strength training and explosive training. Air rower training remains at the same intensity, helping to maintain focus on explosiveness. This improvement aims to stimulate higher muscle and nervous system adaptation, optimizing strength and speed performance at the end of the intervention program. The frequency of Contrast Training is carried out 3x/week for 6 weeks.

Data Collection

Data collection was carried out by measuring leg strength and back strength using a foot dynamometer with the subject pulling the handle with maximum force in the semi-squat position (for leg strength) and the bending position with a straight back (for back strength). The data is generated from the measurement of leg strength and back strength in kilograms (kg). Leg strength, force plates are used through tests such as reverse motion jumps or squat jumps, where the force plates measure the vertical force generated during jumps. From the force and contact time data, power is calculated in watts (force × speed). Meanwhile, VO_2max was measured through a maximum rowing test of 2000 meters, with the subject rowing on an air rower as far as 2000 meters with maximum effort. Travel time is used to predict VO_2max using a formula that takes into account weight, age, and gender, as an indicator of aerobic capacity. These four parameters provide important data for evaluating the muscle strength, explosiveness, and aerobic capacity of rowing athletes.

Statistical Analysis

All statistical analyses are applied with SPSS Version 21.0. The stages of statistical analysis include descriptive tests, normality, and hypothesis tests with paired sample t-tests and independent sample t-tests applied in this study. The data was stated to have a significant difference in hypothesis testing if $p \leq 0.05$.

Results

The results showed that in general, the data on the characteristics of the research subjects in each study group did not show significant differences which can be seen in more detail in Table 1 below. Meanwhile, the results of the analysis of leg strength and back strength, leg strength, and VO_2max between pretest and posttest in each study group are presented in Figure 1-2.

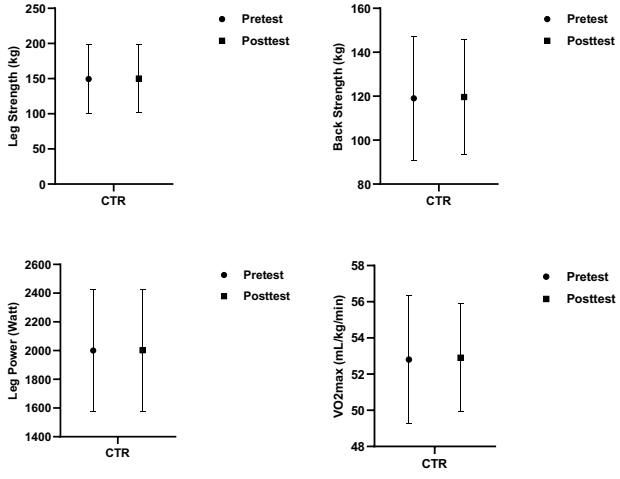

Fig. 1. Differences in leg strength and back strength, leg strength, and VO_2max analysis in the control group (CTR) between pretest and posttest. Description: Data was presented with an mean ± SD. The p-value was obtained by analysis of the paired sample t-test

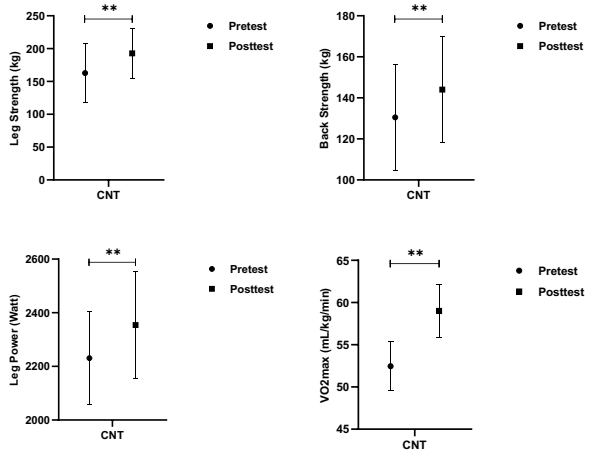

Fig. 2. Differences in leg strength and back strength, leg strength, and VO_2max analysis in the contrast training group (CNT) between pretest and posttest. Description: Data was presented with an mean ± SD. The p-value was obtained by analysis of the paired sample t-test. (**) Significant at pretest ($p \leq 0.001$)

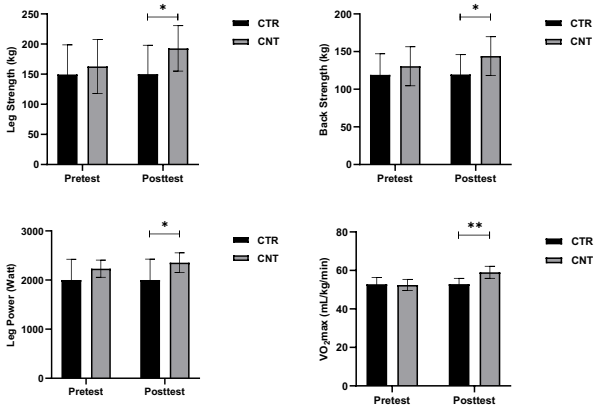

Fig. 3. Differences in leg and back strength, leg power, and VO_2max analysis between CTR vs CNT. Description: Data is presented with an mean ± SD. p-value was obtained by analysis of independent sample t-test (*) Significant at pretest ($p \leq 0.05$). (**) Significant at pretest ($p \leq 0.001$)

Table 1. General characteristics of the subject of study

Parameters	Unit	CTR (n = 11)	CNT (n = 11)	p-value
Age	yrs	20.64 ± 1.21	20.91 ± 1.14	0.591
Height	m	1.77 ± 0.05	1.78 ± 0.04	0.999
Body weight	kg	65.46 ± 5.36	68.73 ± 3.52	0.108
Body mass index	kg/m^2	20.88 ± 1.91	21.91 ± 0.74	0.116
Baseline Leg strength	kg	149.55 ± 49.21	162.73 ± 44.87	0.519
Baseline Back strength	kg	119.05 ± 28.08	130.50 ± 25.85	0.331
Baseline Leg power	watt	2000.46 ± 423.28	2230.64 ± 174.63	0.119
Baseline VO_2max	mL/kg/min	52.81 ± 3.52	52.47 ± 2.91	0.806

Description: Data was presented with an mean ± standard deviation (SD). p-values were obtained by independent sample t-test analysis. RKT: Control group; CNT: Contrast training group

Discussion

This study aims to prove the effect of contrast training by combining conventional deadlift and air rower exercises in increasing leg muscle strength and power as well as VO_2max in rowing athletes. Based on the results of the study, it was found that the group that participated in contrast training showed a significant increase in leg muscle strength compared to the control group. These findings provide strong evidence that the combination of weights and explosive exercises is not only able to increase strength, but also effectively develop the ability of athletes to produce the explosive power needed in the critical phase of rowing (Gee et al., 2014; McGregor et al., 2004).

The rowing movement begins with a leg push, in which the quadriceps, hamstrings, gluteus, and gastrocnemius muscles play a dominant role in generating initial strength. Conventional deadlift training in contrast training programs focuses on strengthening these muscles through high loads (Haff et al., 2001; Swinton et al., 2011), while air rowers add explosive elements that mimic the movement of the paddles themselves. In this context, the increase in strength gained from conventional deadlift training can be optimized through explosive exercises with air rowers, which simultaneously reinforce the relationship between leg strength and power transfer to the upper body during rowing (Seitz & Haff, 2016).

In addition, the results of this study also corroborate the findings of several previous studies that show that combined exercise between heavy weight training and explosive training can improve the performance of athletes in various sports disciplines (Tillin & Bishop, 2009). The increased power gained through contrast training allows athletes to accelerate quickly, especially at the beginning of a race, when maximum explosive thrust is required (Cardoso et al., 2024). In addition, explosive exercises such as those simulated through air rowers also help sharpen the explosive abilities necessary to maintain speed when reaching the finish line.

Contrast exercises that combine conventional deadlifts and air rowers are not only effective in improving leg muscle strength, but can also bring great benefits in posture stability and efficiency of rowing techniques. Previous studies have shown that postural stability is essential for maintaining

optimal performance in sports that involve repetitive movements such as rowing (Wilson et al., 2013). In rowing sports, posture imbalances or incorrect load distribution can not only reduce movement efficiency, but also increase the risk of injury, especially in the lower back (Caldwell et al., 2003). By strengthening the leg muscles through weight exercises such as conventional deadlifts, athletes can maintain better posture during the rowing cycle, ultimately reducing the unbalanced load on the back and upper body (Swinton et al., 2011).

Additionally, the use of air rowers in explosive training helps to improve explosive capabilities, which are indispensable during critical phases such as starting and finishing in races (Chang et al., 2024). These phases require maximum explosive thrust from the leg muscles, and this combination of exercises provides the right stimulus to develop those abilities. Contrast training programs that integrate sport-specific exercises, such as air rowing, also support the improvement of rowing techniques. This supports the claim that explosive training can improve athletes' performance in sports that require endurance and muscle strength, as revealed by previous research (Barra-Moura et al., 2024).

However, the results of this study are inseparable from several limitations that need to be considered. One of the main limitations is the relatively short duration of the study. Although we found a significant increase in leg muscle strength after a contrast training program, we have not been able to explore the long-term effects of this exercise. Previous research has shown that some of the positive effects of explosive and weight-bearing exercises may take longer to maintain or even reach their maximum potential (Tillin & Bishop, 2009). Therefore, longitudinal studies that monitor the development of strength and performance of athletes over a longer period of time are needed to determine whether the benefits of contrast training are long-term or temporary.

In addition, the variability of individual responses to sports programs is also a factor that has not been fully researched in this study. Each athlete may have a different level of adaptation to a training program, depending on factors such as previous training experience, initial physical condition, and fitness level. For example, some athletes may develop muscle strength faster than others, or conversely, some may take longer to achieve optimal results. This is in line with the findings of Seitz and Haff (2016), which highlights that athletes' responses to Post-Activation Potentiation (PAP) and contrast training can vary greatly depending on the individual's condition.

Further research should include a more diverse population of athletes, both in terms of fitness levels and experience in rowing, to get a more comprehensive picture of the effectiveness of these programs. In addition, more in-depth research is also needed to explore how contrast training can be adapted in the preparation phase of the competition and the recovery phase of athletes. In this context, it is important to understand whether this type of exercise is more effective when applied to specific phases in the training cycle, such as when the athlete is at the peak of fitness or in the early adaptation phase (Cormie et al., 2010).

These findings provide a solid basis for coaches to consider contrast training in rowing athlete training programs to improve strength and overall performance. Although the results were positive, the study had limitations, especially regarding the short duration and variability of individual responses that had not been studied in more depth. More research focusing on the long-term effects and adaptation of training in different populations of athletes is needed to reinforce these findings.

Conclusion

Overall, the results of this study suggest that contrast exercises that combine conventional deadlifts and air rowers are an effective method for increasing leg muscle strength and power as well as VO_2max in rowers. In addition to providing benefits in improving explosive power and aerobic endurance, the exercise also supports postureal stability and efficiency of rowing techniques, both of which are important for maintaining optimal performance and reducing the risk of injury. As such, trainers and fitness experts may consider incorporating this exercise program into an athlete's workout routine, especially for those looking to improve their explosive and aerobic endurance in rowing.

Conflict of Interest

The authors state that they have no competing interests.

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Оцінка впливу контрастних вправ з використанням традиційних станових тяг та веслувального тренажера з повітряною системою навантаження на підвищення показників м'язової сили нижніх кінцівок та рівня VO_2max у спортсменів-веслувальників

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

Реферат. Стаття: 6 с., 1 табл., 3 рис., 27 джерел.

Мета дослідження. Мета дослідження полягала в доведенні впливу контрастного тренування з використанням традиційних станових тяг і веслувальних тренажерів з повітряною системою навантаження на підвищення показників м'язової сили нижніх кінцівок і рівня VO_2max (максимальне споживання кисню) у спортсменів-веслувальників.

Матеріали та методи. В рамках цього дослідження застосовано метод «істинного експерименту» з використанням двогрупового перед- і післятестового підходів, що включає в себе дизайн контрольної групи. У дослідженні взяли участь 22 спортсмени-веслувальники віком від 19 до 23 років, які були відібрані з тренувального центру м. Сурабая. Спортсмени проходили програму контрастних тренувань з високою інтенсивністю 85-90 %, що складалися з одного повторення з максимальною вагою (1ПМ), які проводилися тричі на тиждень протягом шеститижневого періоду. У кожній досліджуваній групі визначали силу м'язів нижніх кінцівок та спини, потужність м'язів ніг і показник VO_2max між етапами перед і після проведення курсу тренувань.

Результати. Згідно з результатами дослідження, після виконання контрастного фізичного навантаження встановлено значне покращення показників силових якостей м'язів нижніх кінцівок та спини, потужності ніг та рівня VO_2max порівняно з контрольною групою ($p \leq 0,05$).

Висновки. Отримані дані свідчать про доцільність проведення контрастного тренування, що поєднує стандартні станові тяги та застосування веслувальних тренажерів з повітряною системою навантаження, як ефективного методу підвищення показників сили та потужності м'язів нижніх кінцівок, а також рівня VO_2max у спортсменів-веслувальників, що може сприяти поліпшенню вибухової сили та аеробної витривалості зазначеної категорії спортсменів.

Ключові слова: вибуховість, спортсмени-веслувальники, аеробна витривалість, контрастне тренування.

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Original Scientific Article

Determining the Reliability of Software Electronic Engineering Tools in the Control of Vestibular Disorders in Inclusive Physical Education of Studens

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Abstract

Background. Due to the increase in the proportion of mine-blast injuries sustained during the Russian-Ukrainian war, the number of students in higher education institutions after blast TBI has risen.

Objectives. The study aimed to determine the reliability of the tool for test control of gait parameters, created based on software electronic engineering for students after blast TBI in inclusive physical education.

Materials and methods. The theoretical stage of the research was realized by analyzing the literature on the studied problem, evaluating and synthesizing information from scientific sources. For the empirical part of the experiment, the Dynamic Gait Index test was used to assess gait parameters, dynamic balance, and fall risk. The test results were processed using the methods of statistical mathematical analysis. The experiment involved 30 students (men) after sustaining an explosive traumatic brain injury.

Results. The study presents the developed tool for testing gait parameters using the Dynamic Gait Index, which is based on the integration of various types of software electronic engineering services. The development uses motion, speed, pressure, and touch sensors. The information about the test exercise, recorded by the sensors, is sequentially transmitted by wireless communication means to the controller (Arduino Leonardo based on the ATmega32u4 microcontroller platform) and then to a PC, where the results are displayed on the monitor in digital and graphical form. The development uses a neural network and the Microsoft OneDrive cloud service to process information, which provides processing and storage of large amounts of test control data. The results of the empirical establishment of the Dynamic Gait Index quality measure, the characteristics of reliability and validity that were recorded by the teacher, are significantly inferior in numerical values to the correlation coefficient obtained by the results of the Dynamic Gait Index when the outcomes were recorded using the developed tool.

Conclusions. The introduction of modern software engineering services into inclusive physical education of students represents a significant step forward in implementing an impartial control mechanisms for restoring damaged gait and balance functions, which have been recognized as a leading factor in disability caused by blast TBI, and contributes to ensuring the effectiveness of this process.

Keywords: physical education, student, inclusion, blast TBI, electronic engineering, testing, control, reliability.

Introduction

For 2.5 years in a row, russian troops have been shelling the territory of Ukraine daily. Both the military and civilians are equally likely to suffer from the war and get injured.

Due to the russian aggression, the number of people injured as a result of artillery shelling and bombardment in our country is constantly growing. According to the United Nations Human Rights Monitoring Mission (United Nations Ukraine), from 24 February 2022 to the end of June 2024, at least 33,878 civilians in Ukraine were injured in the hostilities.

Explosions cause injuries to a large number of people at the same time (Blavt et al., 2024). Therefore, mild blast-related concussion (blast TBI), along with being identified as the most common injury among military personnel (VA research on Traumatic Brain Injury), is now becoming one of the most common types of injury among civilians (Gliga, 2024).

Due to the growing proportion of mine-blast injuries during the Russian-Ukrainian war, the number of students in higher education institutions with blast TBI is increasing. The need for additional efforts and attention of higher education institutions aimed at optimizing measures to improve the outcomes for students after blast TBI determines the relevance of scientific research.

Many scientific papers are devoted to the study of students' health (Mykytyuk et al., 2022; Du et al., 2024), which is positioned as a potential of the state. As studied by (Zhytomyrskyi, 2021; Blavt et al., 2022), the problem of improving student health is one of the most important tasks of Ukrainian society has not yet been solved and needs to be addressed as soon as possible.

It has been determined (Blavt et al., 2023) that in the context of large-scale war and post-war reconstruction of the country, higher education not only performs educational functions but is also largely intended to create conditions for the implementation of inclusive policy objectives. The latter has been analyzed quite thoroughly in the scientific literature (Pérez-Gutiérrez et al., 2021; Page, Anderson, & Charteris, 2021; Iacono et al., 2021), according to contemporary narratives.

As an integral part of the process of inclusion, physical education is positioned in scientific sources (Heck & Block, 2021; Lawrence, 2018; Holland, Haegele, Zhu, & Bobzien, 2023) from the perspective of health promotion. It has been determined (Lieberman, Houston-Wilson, & Grenier, 2024; Almond, 2015; Kuntjoro, Soegiyanto, Setijono, & Suhiharto, 2022) that in higher education, physical education provides the function of improving the health of students during their studies.

It has been proved (Fulk et al., 2024) that blast TBI is not treated with medication, and underestimating the risks of this injury leads to long-term consequences, which require timely rehabilitation to avoid future consequences. The need for quality rehabilitation both during the acute period of trauma and in the process of eliminating the consequences has been studied (Ponsford et al., 2024; VA research on Traumatic Brain Injury).

Studies of the course of disorders and the body after blast TBI (Ponsford et al., 2024) indicate an individual course. It has been determined (Fulk et al., 2024) that individual control over the recovery process of these disorders is crucial to ensuring its effectiveness. Shute and Rahimi (2017) found that the appropriate use of control tools is the basis for making informed decisions in the correlation of restoration measures.

Acknowledging the key role of technology (Clara, & Qursum, 2023; Calabuig-Moreno et al., 2020) in promoting inclusive physical education, it has been highlighted (Morgulec-Adamowicz et al., 2024; Yadav, Sharma, & Kumar, 2023) the transformational potential of the latest technologies in shaping the modern progress in this field of knowledge.

The purpose of the study is to determine the reliability of the tool for test control of gait parameters, created based on software electronic engineering for students after blast TBI in inclusive physical education.

Materials and methods

Study participants

30 students after blast TBI, aged from 18 to 23 years from Lviv Polytechnic National University, T. H. Shevchenko National University "Chernihiv Colehium", Drohobych Ivan Franko State Pedagogical University and Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy were involved in the experimental study. Each student's participation in the experiment was agreed with a medical professional after a proper medical examination. The selection of participants for the study sample was based on the principles of inclusivity, ensuring equal access to this process for all students after blast TBI.

The study was planned and carried out following the principles of bioethics set forth by the World Medical Association (WMA-2013) in the "Helsinki Declaration Ethical Principles of Medical Research Involving Humans" and UNESCO in the "General Declaration on Bioethics and Human Rights".

Methods

Taking into account the goal and the interdisciplinary nature of the work, its implementation involves the use of a modern algorithm for the implementation of scientific research at the theoretical and empirical levels of research.

The theoretical analysis of scientific works by leading scientists in the field and the generalization of modern specific approaches to solving a particular problem that has been implemented in practice have substantiated the identified research issues and identified ways of scientific research.

Modeling was used to develop a technical programmable design, and software engineering methods were used to develop software.

Conducting a test procedure to analyze the results of the study is the final stage of the empirical level of the pedagogical experiment. Empirical analysis and synthesis were used to record test data and analyze them.

Statistical mathematical methods were used in the process of processing the empirical results of the experiment.

The generalization of the research results provided a transition from empirical study to data processing, logical

generalizations, analysis and theoretical interpretation of the factual material obtained.

In choosing the method of implementing the pedagogical experiment, we tried to select the most appropriate assessment tool after blast TBI, which is simple, accessible and at the same time, the results of which will form the basis for planning the process of restoring damaged functions and monitoring this progress. Therefore, taking into account the above, the Dynamic Gait Index (DGI) (Physiopedia) was chosen to assess functional stability during walking.

The DGI was developed as a clinical tool for assessing gait, dynamic balance, and fall risk. It assesses not only the usual steady gait but also walking in difficult conditions. (The Dynamic Gait Index (DGI) was developed as a clinical tool to assess gait, balance and fall risk. It evaluates not only the usual steady-state walking but also walking during more challenging tasks.

The test procedure involves performing the functional walking tests are performed by the subject and scored out of three according to the lowest applicable category (Physiopedia). We used a simplified version of the control with four items: stepping over and around obstacles, changing speeds and stair ascent and descent. Each item is scored on a scale of 0 to 3.

It includes eight items, walking on flat surfaces, changing speeds, turning the head in horizontal and vertical directions, walking and turning 180 degrees to stop, stepping over and around obstacles, and stair ascent and descent. The DGI was developed as a clinical tool to assess gait, balance and fall risk. It evaluates not only the usual steady-state walking, but also walking during more challenging tasks (Shirley Ryan AbilityLab).

Research organization

The organizational preparation of the research involved familiarising the students of the study sample with the testing procedure and assessment methodology. At the initial stage, students repeated the test twice. A week later, they took the test for the second time. The experimental factor was the method of fixing the results of DGI, which was implemented by the teacher and the programmable developed tool.

Before performing the DGI, the teacher carefully acquainted the students of the study sample with the procedure for implementing the test process and evaluating the results. The test results were recorded following the principles of anonymity.

Statistical analysis

The result of the statistical processing of the obtained factual material was the identification of numerical values of validity and reliability. The obtained factual material became the basis for the conclusions about the quality of the tests under study. All statistical analyses were performed using SPSS Version 24.0 (IBM Corporation).

Results

It has been shown that blast TBI can be accompanied by cognitive dysfunction, attention deficit, vestibular disorders, etc. There is evidence (Tramontano, Belluscio, Bergamini, Allevi, De Angelis, Verdecchia, Formisano, Vannozzi, & Buzzi, 2022) that most people affected by blast-related TBI experience vestibular disorders: balance and gait disorders are common symptoms after head injury. Thus, balance dysfunction has been identified as one of the most disabling aspects of TBI, especially dynamic balance during walking (Simon, & Harro, 2004).

It has been determined (Zhou, Liu, Zhang, Liu, Wang, Kong, 2021) that gait functions are provided by the complex interaction of the main body systems, such as the nervous, musculoskeletal, cardiorespiratory and vestibular systems. It has been proven that the vestibular system, which encodes signals of movement in space in the central nervous system, ensures gait stability. Therefore, given the above, our research is aimed at ensuring objective, unbiased monitoring and assessment of the state of the vestibular apparatus of students after a blast TBI.

The chosen research tool, the DGI, tests the ability to maintain balance while walking, responding to different task requirements in different dynamic conditions. The DGI is considered (Magnani, van Dieën, & Bruijn, 2023) to be a useful test for monitoring vestibular and balance disorders. It has been shown (Simon, & Harro, 2004) that the DGI is an effective tool to measure dynamic balance in individuals with brain injury. Evidence from (Chiu, Fritz, Light, & Velozo, 2006) suggests that balance assessment in multitasking conditions is a more sensitive indicator of balance development and fall risk than single-task control.

The outcome of our study was the development of a tool for testing gait parameters using DGI based on the use of software electronic engineering tools.

The development was guided by the need to control uneven movement (changing speeds), head turns in horizontal and vertical directions, walking and turning 180 degrees to stop. With this in mind, motion sensors are placed directly on the student to control the body's position in space (Mykytyuk et al., 2022).

On the obstacles required for the test (stepping over and around the obstacles), proximity and presence sensors are mounted on top and on one side of the cube-shaped obstacles. The student's movement pattern during the test process is shown in Fig. 1. The color change of the sensor signals the correct execution of the exercise, in particular, stepping over the obstacle and going around it from both sides.

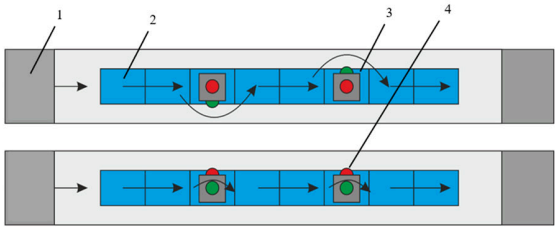

Fig. 1. Scheme of the student movement during the test process: 1 – start, 2 – direction of student movement, 3 – obstacles, 4 – sensors

Sensors placed on the obstacles allow you to automatically determine the correctness of the exercise and possible deviations. The operation of both sensors on an

obstacle indicates incorrect movement, deviation from the trajectory, coordination, etc. To analyze the speed of overcoming obstacles, it is possible to place speed sensors on the obstacles.

To automate the DGI test, which involves the use of steps, pressure sensors are placed on the steps, directly on the plane (Fig. 2). In this case, they detect the moment the student steps on the step, recording full contact with the surface of the step with both feet. Receipt of two consecutive signals from the same step indicates the absence of the necessary alternation of feet provided by the test.

To determine the speed of the distance covered, speed sensors are placed on the steps. The speed sensors are placed on the steps along the sideline, and the touch sensors are placed on the handrails. The signal from these sensors, if the test subject touches the handrail during the test, will indicate the use of the handrail.

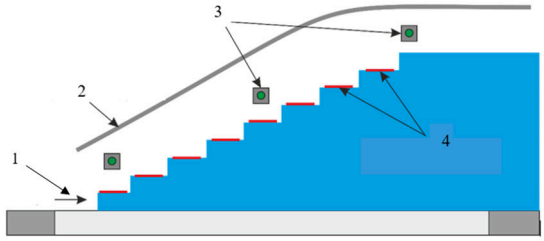

Fig. 2. Scheme of implementation of the test process with the use of steps: 1 – start, 2 – direction of student movement, 3 – touch sensors, 4 – speed sensors, 5 – pressure sensors

The implementation of DGI testing using the developed tool is as follows: motion sensors are placed on the student's body, which record information during the test exercise. The start of the test, its end and the passage of control points are recorded to the nearest millisecond.

The signal detected by the sensors is transmitted to the controller via a contactless Bluetooth data network. In our development, we used the Arduino Leonardo, a controller based on the ATmega32u4 microcontroller platform, which has 20 digital inputs/outputs and 32 kB of flash memory. The memory of this platform must be read and written using the Electrically Erasable Programmable Read-Only Memory library. This type of memory can be cleared and filled with information several tens of thousands of times. Thus, we ensure the storage and availability of student testing information throughout the entire course of study, which is stored for the required period and is available at any time.

The platform is controlled by software using an Arduino. The signal processed by the controller is sent to a PC, where, based on the results of computer calculations, we get the result in digital and graphical form on the PC screen. The development uses image analysis systems based on the latest technologies of our time – neural networks.

In our development, the neural network is used to process information, extract patterns and make decisions based on the received DGI data. We have used the ability of neural networks to work based on large amounts of data, implementing data analysis and ensuring their reliability and objectivity in real-time.

The use of the Microsoft OneDrive cloud service in the development ensured the processing and storage of significant amounts of test control data, which are available to the teacher at any time. In addition, files can be synchronized with a PC and accessed from a web browser or mobile device.

The tool works as follows (Fig. 3). Sensors are placed on the student's body. The information about the test exercise, recorded by the sensors, is transmitted wirelessly to the controller and to the PC, where the results are displayed on the monitor in digital and graphical form.

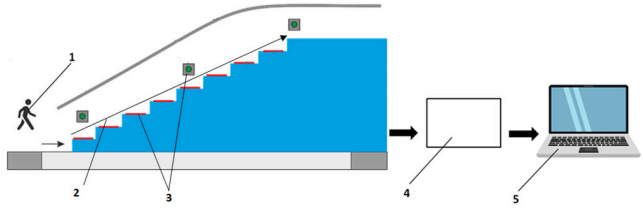

Fig. 3. Implementation of DGI testing using the developed tool: 1 – student, 2 – test distance, 3 – a system of sensors, 4 – controller, 5 – PC

The results of the empirical establishment of the DGI quality measure (Table 1), the characteristics of reliability and validity that were recorded by the teacher, are significantly inferior in numerical values of the correlation coefficient obtained from the DGI results when the results were recorded using the developed tool.

Table 1. Reliability of the DGI for students with disabilities after blast TBI (n = 30)

Statistical pparameters	Test tasks stepping and measurement results (points)							
	around obstacle		over obstacle		stairs Gait		change in gait speed	
	T	DT	T	DT	T	DT	T	DT
M	1.95	2.12	1.78	2.01	1.33	1.57	1.45	1.81
S	0.26	0.11	0.33	0.19	0.27	0.31	0.61	0.37
V (%)	31.5	20.2	29.7	21.3	33.2	20.8	32.7	18.6
				Rtt				
reliability	0.381	0.899	0.412	0.876	0.441	0.885	0.443	0.878
validity	0.211	0.605	0.242	0.617	0.285	0.641	0.227	0.626

*Note: T – registration of the results by the teacher, DT – registration of the results using the developed tool

Discussion

The powerful negative impact on public health of the Russian Federation's war in Ukraine, which has resulted in massive injuries and maims, has focused researchers' attention on the problem of health maintenance and recovery (Blavt, & Gurtova, 2024). Our study expands the information (Pérez-Gutiérrez, Castanedo-Alonso, Salceda-Mesa, & Cobo-Corrales, 2021; Heck, & Block, 2021; Lieberman, Houston-Wilson, & Grenier, 2024) on the leading role of physical education tools for students with disabilities in restoring their health.

The conducted scientific research is consistent with the scientific data (Moriña, 2016; Nilholm, 2020; Goodwino, & Watkinson, 2000) on the need for permanent changes in inclusive higher education. We support scientific approaches to the potential of inclusive physical education in implementing the above (Penney, Jeanes, O'Connor, & Alfrey, 2017; Pocock, & Miyahara, 2017; Almond, 2015).

Modern technologies in inclusive physical education are considered (Calabuig-Moreno, González-Serrano, Fombona, & García-Tascón, 2020; Almusawi, Durugbo, & Bugawa, 2021; Yu, Kulinna, & Lorenz, 2018) as a powerful catalyst that bridges gaps and creates opportunities. Such opportunities are provided by the introduction of the latest advances in unified information technology, telecommunications and software integration (Kim, Kim, Kim, Kim, Kim, & Han, 2012; Gil-Espinosa, Nielsen-Rodríguez, Romance R, Burgueño, 2022; Cabrera Ramos, Álamos Vásquez, Ariane, & Lagos Rebolledo, 2019).

The obtained scientific results expand the information (Son, Kim, Noh, Kim, Lim, & Han, 2022; Belluscio, Bergamini, Tramontano, Orejel Bustos, Allevi, Formisano, Vannozzi, & Buzzi, 2019; Ho-Dong, Eunjung, & Byoung-Hee, 2024) on ensuring the objectivity and impartiality of walking parameters control based on the integration of the latest information technologies into this process.

Our search is based on the information about the association between vestibular function and gait characteristics (Zhou, Liu, Zhang, Liu, Wang, & Kong, 2021; Magnani, Bruijn, van Dieën, & Forbes, 2021; Magnani, van Dieën, & Bruijn, 2023).

Testing of gait parameters using DGI has been applied to control in across diagnostic groups (Matsuda, Taylor, & Shumway-Cook, 2014), middle-aged patients with stroke (Jin, Lee, Park, Lee, & Lim, 2023), children (Lubetzky-Vilnai, Jirikowic, & McCoy, 2011), with cerebellar ataxia (Reoli, Therrien, Cherry-Allen, Keller, Millar, & Bastian, 2021), patients with normal pressure hydrocephalus for cerebrospinal fluid diversi (Chivukula, Tempel, Zwagerman, Newman, Shin, Chen, Gardner, McDade, & Ducruet, 2015).

The reliability of the DGI has been studied for different groups of people, including people with chronic stroke (Jonsdottir, & Cattaneo, 2007; Alghadir, Al-Eisa, Anwer, & Sarkar, 2018), vestibular disorders (Wrisley, Walker, Echternach, & Strasnick, 2003; Marchetti, Lin, Alghadir, & Whitney, 2014), and brain injury (Simon, & Harro, 2004; Belluscio, Bergamini, Tramontano, Orejel Bustos, Allevi, Formisano, Vannozzi, & Buzzi, 2019), in older men (Abdiani, Golpayegani, & Khajavi, 2014), male veterans (Chiu, Fritz, Light, & Velozo, 2006), with hemiparesis after stroke (Flansbjer, Holmbäck, Downham, Patten, & Lexell, 2005), with multiple sclerosis (Soltanpour, Kalantari, & Roostaei, 2019).

We first investigated the use of DGI to assess the state of gait and balance parameters and determined the level of reliability for students after blast TBI, which is the basis for ensuring impartiality and objectivity of control in the physical education of students after blast TBI.

Conclusions

Implementing an inclusive educational process for students affected by war is a challenge for higher education institutions. Even though the war is ongoing, the need to implement a set of measures aimed at protecting the health of participants in the educational process is due to the permanent increase in the number of students who have sustained war-related injuries, including blast TBI, in higher education institutions.

In the case of blast-related injuries, it is important to understand the vestibular consequences of blast TBI, as blast TBI is very typical of modern wars, particularly the Russian-Ukrainian war. Our research is based on the fact that gait and balance dysfunction is recognized as a leading factor in disability after blast TBI. It has been found that the introduction of modern technological solutions for the implementation of impartial control of the process of restoring damaged functions is a factor in ensuring the effectiveness of this process.

The article presents the developed constructive solution, which is implemented on the basis of software electronic engineering, providing processing of large arrays of data obtained from the test results, and, thanks to cloud services that implement high-speed computing, makes it possible to obtain objective, unbiased test control results in real-time.

The reliability of the developed design for the control of vestibular disorders in inclusive physical education of students after blast TBI was established at the level that, according to the evaluation scales, is 'high' in terms of reliability and validity. These results significantly exceed the established values of test-retest reliability when the results are recorded directly by the teacher.

Conflicts of Interest

No conflicts of interest exist.

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Визначення достовірності інструментів програмної електронної інженерії у контролі вестибулярних розладів у інклюзивному фізичному вихованні студентів

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

Реферат. Стаття: 9 с., 1 табл., 3 рис., 59 джерел.

Через зростання питомої ваги мінно-вибухових поранень під час російсько-української війни, збільшується чисельність студентів у закладах вищої освіти після після вибухової черепно-мозкової травми.

Мета статті полягала у визначені достовірності інструменту тестового контролю параметрів ходи, створеного на основі програмної електронної інженерії для студентів після після вибухової черепно-мозкової травми у інклюзивному фізичному вихованні.

Матеріали та методи. Теоретичний етап дослідження реалізовано аналізом літератури з досліджуваної проблематики, аналізом та синтезом інформації наукових джерел. Для реалізації емпіричної частини експерименту використано тестування з використанням Dynamic Gait Index для оцінки параметрів ходи, динамічної рівноваги та ризиків падіння. Результати тестування опрацьовано методами статистичного математичного аналізу. До експерименту залучено 30 студентів (чоловіки) після вибухової черепно-мозкової травми.

Результати. Представлена розроблена конструкція для тестування параметрів ходи з використанням Dynamic Gait Index, що ґрунтується на інтеграції різноманітних видів сервісів інструментів програмної електронної інженерії. У розробці використано сенсори руху, швидкості, тиску та дотику. Інформація про виконання тестової вправи, зафіксована сенсорами, передається бездротовими засобами зв'язку послідовно на контролер (Arduino Leonardo на базі мікроконтролерної платформи ATmega32u4) та далі на персональний комп'ютер, де результати представляються на моніторі у цифровому та графічному вигляді. У розробці для обробки інформації, використано нейромережа та хмарний сервіс Microsoft OneDrive, яким забезпечують обробку та зберігання значних обсягів даних тестового контролю.

Результати емпіричного установлення міри добротності Dynamic Gait Index, з'ясовані характеристики надійності та валідності, які реєструвались викладачем, значно поступаються у числових значеннях коефіцієнту кореляції, який отримали за результатами Dynamic Gait Index у разі, коли результати реєструвались з використанням розробленої конструкції.

Висновки. Упровадження сучасних технологічних рішень задля реалізації неупередженого контролю процесу відновлення ушкоджених функцій ходи та рівноваги, що визнана провідним фактором інвалідизації після blast TBI, є чинником забезпечення ефективності інклюзивного фізичного виховання студентів.

Ключові слова: фізичне виховання, студент, інклюзія, вибухова черепно-мозкова травма, електронна інженерія, тестування, контроль, достовірність.

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A Comparative Analysis of the Effects of Reduced Positional Games and Traditional Training on the Physical and Technical Performance of Young Soccer Players in Training

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Abstract

Background. Implementing reduced positional games as a training method in modern soccer has been represented as an important determinant in improving and developing the skills of young soccer players in training.

Objectives. The study aimed to determine the effect of a 12-week period of reduced positional games on the physical and technical performance of young soccer players in training.

Materials and methods. Forty male soccer players in training of the Moroccan U17 national championship club CFC participated in this study. The players were divided, according to their club, into an experimental group with reduced positional games and a control group engaged in traditional training. Both teams took part in training sessions three times a week for 12 weeks. Each session lasted 90 minutes. Before and after the intervention, both groups performed physical tests (Yo-Yo intermittent test, linear sprint of 10 m, 20 m and 20 m with a change of direction, SJ — Squat Jump, CMJ — Countermovement Jump) and technical tests (LSPT — The Loughborough Soccer Passing Test, LSST — The Loughborough Soccer Shooting Test), all performances achieved by both groups were evaluated. The OptoJump, My Jump application, and technical test grid were used to quantify the results.

Results. The results revealed significant improvements in MAS ($p < .001$; $n^2 = 0.017$); 10 m sprint ($p < .001$; $n^2 = 0.102$), 20 m sprint ($p = 0.002$; $n^2 = 0.022$), 20 m sprint ($p < .001$; $n^2 = 0.022$), 20 m sprint with a change of direction ($p < .001$, $n^2 = 0.087$), as well as an increase in height in the SJ ($p < .001$; $n^2 = 0.012$) and CMJ ($p < .001$; $n^2 = -0.016$). Compared to the LSPT results, an increase in the number of passes was observed in the experimental group ($p < .001$; $n^2 = 0.175$) and a notable enhancement in pass control ($p < .001$; $n^2 = 0.131$). The LSST test showed a significant increase in shooting performance ($p = .001$; n^2 (right foot) = 0.045; n^2 (left foot) = 0.049) and a decrease in shooting time ($p = .001$; n^2 (right foot) = 0.045, n^2 (left foot) = 0.005). Post-hoc tests demonstrated that training involving reduced positional games resulted in greater improvements in the SJ, CMJ, 10 m sprint, 20 m sprint, 20 m sprint with a change of direction, LSPT, and LSST.

Conclusions. The findings indicate that a 12-week training program based on reduced positional games, incorporating 3 sessions per week, led to a considerable enhancement in the physical and technical performance of young soccer players in training. Therefore, it is recommended to coaches and physical trainers to include training sessions based on reduced positional games into the team's annual program.

Keywords: training, reduced positional games, young footballers, physical, technical.

Introduction

Training methodology plays an increasingly important role in the world of soccer. In the past, the disparity in performance between teams depended largely on the talent of the players. Some teams stood out for their more intense physical, technical, tactical, or psychological commitment. Today, all four parameters are equally important.

A team's overall performance can be affected by a number of factors, such as poor physical condition, weak technical skills, a lack of tactical understanding, or a mental deficiency in a player, depending on his or her position on the pitch and the patterns of play and instructions from the coaches. To succeed at the highest level of modern soccer, certain qualities are essential. When a player fails to meet the

required standards in one of these qualities, this can have an impact on the team's overall performance (Abarghoueinejad et al., 2021). A player who cannot fulfill his role will upset the collective balance (Gréhaigne & Godbout, 2021), depending on the positions occupied on the pitch and the strategies put in place by the coach.

To date, different training methods have been used to improve physical performance in soccer (Milanovic et al., 2015; Morgans et al., 2018). In addition, matching these training models with players' general skills can promote progression during matches. Today, more and more soccer coaches are opting for reduced games as a teaching method. Games played in small groups with position are essential for the development of young footballers during their training. Through these exercises, young players have the opportunity to come into contact with the ball more frequently, thus improving their ball handling skills, and to develop understanding of space and movement, as well as overall game intelligence in relation to physical, technical, tactical, and mental performance; an alternative proposed is reduced games with position (RGP). This approach offers a more realistic representation of the game than conventional reduced games or traditional training. In recent years, there has been an increase in the popularity of RGP due to their ability to recreate real game situations (Olthof et al., 2015).

Reduced games with position (RGP), on the other hand, aim to strengthen the specific skills of players within a team, using small groups. These games are characterized by a reduced number of players and a smaller playing surface, and a positioning of players in the different sections of the field while respecting the roles defined by the coach, namely roles in defense, midfield, and attack. This positioning promotes interactions between players in restricted spaces. The aim is to mimic the movements and displacements observed in real game situations (Clemente et al., 2014).

High-intensity reduced games with position (RGP) enhance players' fitness, both aerobically and anaerobically. Kokstejn et al. (2024) observed that even low-intensity games can improve overall fitness, as players continuously perform high-intensity actions within them. Furthermore, these types of games contribute to the development of endurance, speed, and agility, essential qualities for excelling in soccer (Clemente et al., 2021). By reducing the number of players, RGP also offer participants the opportunity to become more involved in the game. Extensive studies have suggested that they can be used to improve physical skills in restricted game environments, which require reactions and quick decision-making. The comparison is made between intensive playing conditions, and this helps to improve players' overall fitness.

In terms of technical performance, several studies highlight the technical benefits of RGP for young players. According to Sarmento et al. (2018), it was found that young players involved in RGP experienced notable improvements in their technical performance, as well as in their ability to understand the tactical aspects of the game. Players need to develop technical skills such as ball control, passing accuracy, and their ability to maintain possession in a tight space despite pressure. This is crucial to their personal and collective technical training, as it helps them improve not only their individual performance but also harmonize their actions with those of the team (Sgrò et al., 2018; Praça, G et al., 2016).

Role-playing on the pitch helps players acquire skills and try out different tactical combinations and approaches. By encouraging players to make quick and accurate decisions, this improves their tactical understanding of the game. According to Ometto et al. (2018), players are able to adapt quickly to changes in the game and respond better to tactical challenges posed by their opponents thanks to these direct experiences. RGP are a derivative version of classic RGP. They require greater mobility while observing the positions assigned to each player. In a live role-playing game, progression depends on the position occupied by the player, the transitions made, individual technical skills, and the collective intelligence of the players.

It can be advantageous to use traditional training methods to improve individual technical skills. According to Slaidins and Fernate (2021), it is suggested that repeated practice of individual exercises can lead to significant improvements in technical skill. In 2021, Oliva-Lozano and his team made an interesting discovery of traditional training that proved to be particularly effective in improving both shooting accuracy and dribbling skills (Oliva-Lozano, 2021).

While these methods may improve specific skills, they may not guarantee the contextual application that is offered by RGP. According to Grün (2016) and More-Chevalier (2020), it is possible for players to succeed in acquiring a technical skill but encounter difficulties when it comes to applying it effectively in a real match situation.

Researchers advocate an integrated approach because of the unique advantages offered by RGP and traditional training methods. According to Clemente et al. (2021), by combining the contextual and decision-making advantages of RGP with conventional training methods geared towards improving targeted skills, it is possible to develop a more comprehensive training program. This hybrid approach ensures that players improve their physical and technical skills while developing tactical understanding, contributing to an overall improvement in performance.

Taking these various observations into account, it is clear that reduced games with position can help improve the physical, technical, tactical, and mental skills of young soccer players in training. This study aims to analyze the impact of RGP on the development of physical and technical qualities in young players in training. We seek to determine whether RGP can provide a significant competitive advantage over traditional training methods.

Materials and Methods

Study Participants

The study included 40 soccer players in the under-17 category from a team of 20 players from the federal club of Kenitra and another team of 20 players from the federal club of sale, Morocco, with at least 3 years' experience in competitions. They were selected by their technical manager, so that the teams would be balanced in terms of player positions (defenders, midfielders and strikers). This precaution was taken to enable the teams to maintain a high level of competitiveness and concentration during the matches. To reduce variability between participants, the same teams trained 3 times a week. During the sessions, training with

reduced games with position was introduced into the program for the experimental team, and conventional training for the control team. All participants were tested as part of the team training program. Data were collected between winter and spring (December 2023-March 2024). The study was approved by the local ethics committee, and all participants were informed of the experimental protocol and gave informed consent for participation in the study. Appropriate ethical standards were observed.

Protocol

To measure the influence of reduced games with position on players' physical and technical qualities, the researcher set up a series of tests. These tests, carried out before and after a 12-week training intervention based on RGP for the experimental group and conventional training for the control group, were designed to assess the players' physical and technical performance. Anthropometric measurements only describe the characteristics of the sample; this parameter is not taken into account in the study, serving only to show the balance between the players of the two teams, a yo-yo test (YYIRT1) to determine maximum aerobic speed (MAS), assessment of muscular power and elasticity of the lower limbs using the squat jump test (SJ) and the counter movement jump test (CMJ). Linear and angular velocity were assessed over distances of 10 m, 20 m linear and 20m with change of direction. Technical tests using the Loughborough Soccer Passing Test (LSPT) for ball control and the Loughborough Soccer Shooting Test (LSST) for shooting, and a game test in the form of an official match (treatment team and control team). The same tests will be repeated after 12 weeks of training to assess the effect of reduced games with position on the players' physical and technical performance.

Design

The first game situation [situation 1: maintaining possession of the ball: Rondo] was conducted according to a set of game rules. The second game situation [situation 2: ball possession in a defense, midfield and attack configuration, example 5vs5 with the following layout (2-1-2)], the third game situation [situation 3: Rondo with transition 6vs6 with a configuration: 4vs2(1-2-1vs2) in a square, which becomes a 6vs4(2-2-2vs4) on a rectangular pitch that projects to a 6vs4+2(2-2-2vs4+2)] and the fourth specific game situation [situation 4: 7vs7(2-3-2, with goalkeeper)] matches, in the different game situations we used configurations without goal and with small and large goal. This study did not analyze goalkeeper performance. The games were preceded by 15 minutes of standardized warm-up and took place in the afternoon.

Physical Tests

Yo-Yo Intermittent Recovery Test (YYIRT1): This is a field test designed to measure players' aerobic capacity. The yo-yo test was carried out on a synthetic pitch. The test consisted of two repeated runs of 20 m (out and back) at progressively increasing speed, controlled by a sound signal from a tape recorder and separated by a 10-second recovery time. Running speed was increased in stages, and players continued the test until they were no longer able to keep up with the pace imposed by the audio file. When a player failed to reach the finish line on time on two consecutive occasions, the distance covered (m) was recorded as the test result. The test was preceded by a standardized 10-minute warm-up (Gogte, Srivastav, & Miyaru, 2017).

Linear sprint speed test: Players performed two linear sprints over distances of 10m and 20 m. The fastest time of the two trials was recorded for the final analysis (Drozd, Krzysztofik, Nawrocka, Krawczyk, Kotuła, Langer, & Maszczyk, 2017).

Speed of change of direction (VCD) test: Georges Cazorla's VCD test is a football-specific tool for assessing players' ability to change direction and re-accelerate at high speed. The course measures 20 meters in actual running, but the actual distance covered is 16 meters. The player had to complete the course as quickly as possible, making 4 changes of direction. Players conducted two trials, and the fastest result was selected for further analysis. An adequate warm-up is crucial for preventing injuries prior to the test. A proper warm-up is essential before carrying out the test.

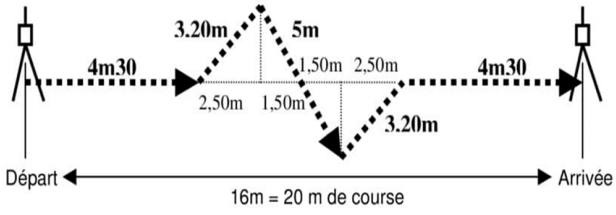

Fig. 1. Schematic representation of the speed test with direction change (Semenick, 1990)

Vertical jump tests: the vertical jump test is widely used to assess leg strength. Measurements were taken prior to the squat jump (SJ) and counter-movement jump (CMJ) training programs. For the SJ, players remained in a static semi-squat position with a knee flexion angle 90 for 1 second before executing a maximal vertical jump. For the CMJ, players started in a standing position and had to perform a downward movement to a semi-crouched position followed by a full, explosive vertical extension of the legs. Hands on hips during SJ and CMJ. Players performed two jumps and the average of the two jumps was taken for the final analysis. To assess jump height, Opto-jump and the My jump application were used to deduce jump height.

Technical Tests

Loughborough Soccer Pass Control Test (LSPT): The LSPT test was developed and validated by Ali, Foskett, and Gant (2008) to assess various football-related technical skills (Figure 2). The LSPT examines various soccer skills, including the assessment of passing accuracy and technique. Assessment of a player's ability to handle the ball in motion. Evaluation of the speed with which a player processes information and makes decisions during play. This is a comprehensive test that provides information on a soccer player's general skills. Players started the LSPT with the ball

in the center of the test area, then were asked to complete 16 passes against benches with colored parts on each bench. LSPT performances included the original time to determine the 16 passes, the penalty time, and the execution time. Players were asked to complete the test as quickly as possible with the fewest errors.

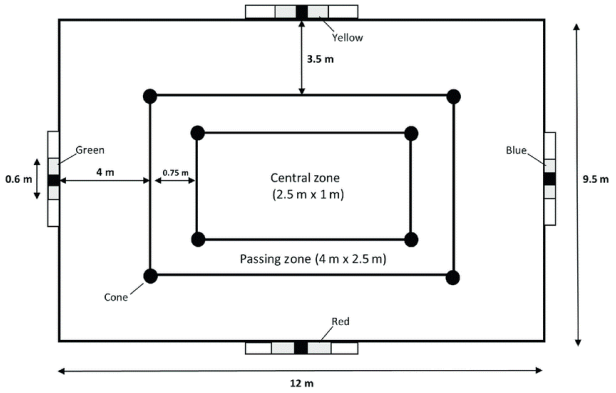

Fig. 2. Schematic representation of the Loughborough Soccer passing Test (LSPT)

Loughborough Soccer Shooting Test (LSST): The Loughborough Soccer Shooting Test (LSST) is widely used to assess footballers' shooting skills (figure 3). It combines performance time with positive and negative point scoring for technical performance as well as errors. The LSST was designed to assess a player's accuracy, strength and consistency when shooting at goal.

Statistical Analysis

Data were analyzed by the repeated-measures ANOVA II test, and post hoc analyses (pairwise comparison) were analyzed by the Bonferroni test. All data analyses were performed with SPSS 24 (IBM Corp., Armonk, NY, USA). A significance level of 5 % was adopted for cases.

Results

The results in Table 1 highlight the impact of training on the physical performance of both the experimental and control groups, using repeated measures via ANOVA II, followed by Bonferroni post hoc tests. The results reveal significant improvements in several parameters for the experimental group, while the control group shows little change.

Analysis of changes in the physical variables of young footballers in training

Maximum Aerobic Speed (VMA). The results show an increase in VMA for both groups after training. Repeated measures ANOVA revealed a significant effect of training ($F_{(1,34)} = 18.602$, $p < 0.001$), but the interaction between training and groups was not significant ($p = 0.811$). Post hoc comparisons indicate a significant average increase in VMA for the experimental group, rising from 15.749 to 15.932, representing a significant increase of 1.16 % ($p_{bonf} < 0.0041$).

10-meter speed. Analysis of 10-meter speed performance showed a significant decrease in time for the experimental group (from 2,072 to 1,971 seconds), corresponding to a reduction of 4.87 %, while the control group remained stable. Repeated measures ANOVA revealed a significant effect of training ($F_{(1,34)} = 45.061$, $p < 0.001$) and a significant interaction between training and groups ($F_{(1,34)} = 9.222$, $p = 0.005$). Post hoc tests confirmed that the reduction in speed time was significant for the experimental group ($p_{bonf} < 0.001$).

20-meter speed. A similar trend was observed for 20-meter speed, with a decrease in time for the experimental group (from 3,470 to 3,392 seconds), a reduction of 2.25 %, and stability for the control group. ANOVA showed a significant effect of training ($F_{(1,34)} = 11.719$, $p < 0.002$), but the interaction between training and groups was not significant ($p = 0.328$). Post hoc tests show a significant decrease for the experimental group ($p_{bonf} < 0.001$).

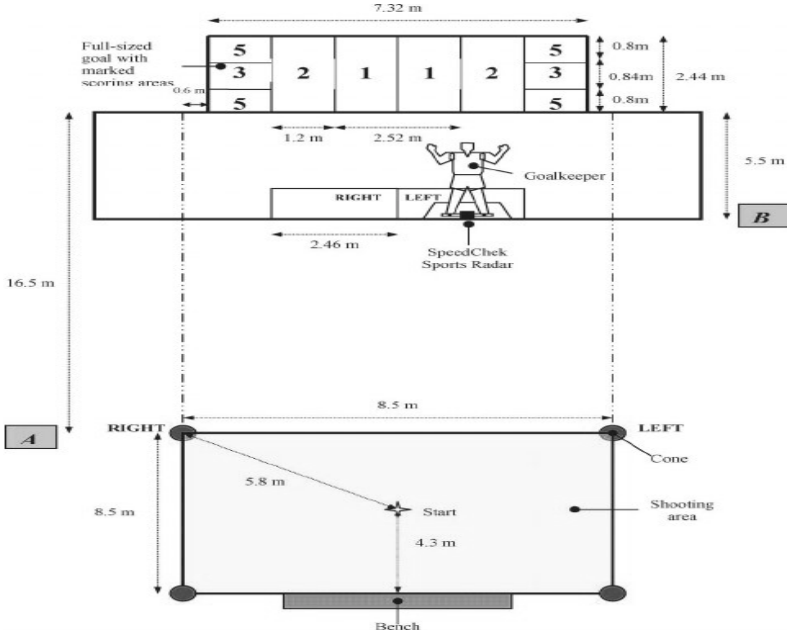

Fig. 3. Schematic representation of the Loughborough Soccer Shooting Test (LSST)

Table 1. Effect of a 12-week training program based on reduced games with position versus a traditional training program on the physical qualities of players in training

Variables	Group	Pré	Post	Cohen d	ANOVA p-value (n^2)		
					Formation	Group	Formation x group interaction
VMA	Control	15.705	15.910	-0.268	<.001 (0.001)	0.896 (0.004)	0.811 (0.005)
	Exp	15.749	15.932	-0.240			
V10 m	Control	2.092	2.053	0.374	<.001 (0.102)	0.125 (0.054)	0.005 (0.021)
	Exp	2.072	1.971	0.992			
V20 m	Control	3.851	3.709	0.423	0.002 (0.022)	0.003 (0.217)	0.328 (0.002)
	Exp	3.470	3.392	0.233			
VCD20 m	Control	5.864	5.761	0.464	<.001 (0.087)	0.515 (0.011)	0.023 (0.005)
	Exp	5.847	5.681	0.742			
SJ	Control	34.889	36.556	-0.236	<.001 (0.012)	0.931 (0.001)	0.620 (0.001)
	Exp	35.222	36.611	-0.197			
CMJ	Control	38.222	39.556	-0.179	<.001 (0.016)	0.991 (0.003)	0.012 (0.001)
	Exp	37.667	40.056	-0.321			

VMA: maximun aerobic spead; V10 m: linear sprint speed test; V20 m: linear sprint speed test; VCD20 m: speed of change of direction; SJ: squat jump; CMJ: countre mouvement jump

20-meter speed with change of direction. For angular 20-meter speed, the results also indicate a significant reduction in time for the experimental group (from 5,847 to 5,681 seconds), representing a reduction of 2.84 %, but not for the control group. Repeated measures ANOVA reveals a significant effect of training ($F_{(1,34)}$ = 106.808, p < 0.001) and a significant interaction ($F_{(1,34)}$ = 5.672, p = 0.023). Post hoc comparisons confirmed that the improvement was significant for the experimental group (p_{bonf} < 0.001).

Squat jump (SJ). Regarding static jump performance, a significant increase was observed for the experimental group (from 35.222 to 36.611 cm), i.e. an increase of 3.94 %, while the control group remained stable. ANOVA shows a significant effect of training ($F_{(1,34)}$ = 30.303, p < 0.001), but no significant interaction (p = 0.620). Post hoc results indicate that the increase in SJ is significant for the experimental group (p_{bonf} < 0.001), although training improved jumping performance for both groups.

Countermovement jumping (CMJ). Finally, the increase in countermovement jumping (CMJ) performance was also significant for the experimental group (from 37.667 to 40.056 cm), representing an increase of 6.34 %. ANOVA revealed a significant effect of training ($F_{(1,34)}$ = 87.817, p < 0.001) and a significant interaction between training and groups ($F_{(1,34)}$ = 7.062, p = 0.012). Post hoc tests confirmed that the increase was significant for the experimental group (p_{bonf} < 0.001), suggesting that this type of training has a specific positive influence on CMJ for this group.

Analysis of changes in the technical variables of young footballers in training

With regard to technical performance, the results in Table 2 highlight the impact of training on the technical performance of both the experimental and control groups, using repeated measures via ANOVA II, followed by Bonferroni post hoc tests. The results reveal significant improvements in several parameters for the experimental group, while the control group shows little improvement.

Number of passes. The results show a significant increase in the number of passes for the experimental group after training, rising from 10,000 to 12,667, an increase of 21.05 %. In contrast, the control group remained stable. The repeated measures ANOVA indicates a significant effect of training ($F_{(1,34)}$ = 39.535, p < 0.001) and a significant interaction between training and groups ($F_{(1,34)}$ = 4.421, p = 0.043). Post hoc tests confirmed that the increase was significant for the experimental group (p_{bonf} < 0.001).

Pass control time. The experimental group showed a significant reduction in pass control time, from 49.284 to 43.012, a reduction of 12.73 %, while the control group remained stable. Repeated measures ANOVA revealed a significant effect of training ($F_{(1,34)}$ = 39.014, p < 0.001) and a significant interaction between training and groups ($F_{(1,34)}$ = 28.689, p < 0.001). Post hoc comparisons show that this reduction is significant for the experimental group (p_{bonf} < 0.001).

Shooting with the right foot. Right-foot shooting performance increased significantly for the experimental group, from 7.833 to 12.500, representing an increase of 59.58 %, while the control group remained stable. ANOVA shows a significant effect of training ($F_{(1,34)}$ = 73.174, p < 0.001) and a significant interaction between training and groups ($F_{(1,34)}$ = 35.545, p < 0.001). Post hoc results indicate that the increase is significant for the experimental group (p_{bonf} < 0.001).

Shooting with the left foot. Shooting with the left foot also showed a significant increase for the experimental group, rising from 5.833 to 10.056, an increase of 72.40 %. The control group remained stable. Repeated measures ANOVA revealed a significant effect of training ($F_{(1,34)}$ = 74.293, p < 0.001) and a significant interaction ($F_{(1,34)}$ = 23.885, p < 0.001). Post hoc comparisons show that the increase is significant for the experimental group (p_{bonf} < 0.001).

Table 2. Effect of a 12-week training program based on reduced games with position versus a traditional training program on the technical qualities of players in training

Variables	Group	Pré	Post	Cohen d	ANOVA p-value (n^2)		
					Formation	Group	Formation x group interaction
NBR PASSE	Control	9.941	10.611	-0.391	<.001 (0.175)	0.043 (0.070)	<.001 (0.063)
	Exp	10.000	12.667	-1.566			
TPS DE CONTROLE	Control	49.361	48.879	0.122	<.001 (0.131)	0.018 (0.101)	<.001 (0.096)
	Exp	49.284	43.012	1.594			
TIR P D	Control	7.889	8.722	-0.249	<.001 (0.133)	0.091 (0.061)	<.001 (0.064)
	Exp	7.833	12.500	-1.394			
TIR P G	Control	5.833	7.000	-0.380	<.001 (0.153)	0.126 (0.049)	<.001 (0.049)
	Exp	5.833	10.056	-1.376			
TPS T P D	Control	9.363	9.236	0.136	<.001 (0.045)	0.186 (0.041)	0.018 (0.022)
	Exp	9.254	8.559	0.741			
TPS T P G	Control	9.190	9.184	0.007	0.447 (0.005)	0.498 (0.010)	0.473 (0.004)
	Exp	9.132	8.921	0.257			

$p < 0.05$, LSPT: Loughborough soccer pass control test; LSST: Loughborough soccer shooting test; NP: number of pass; PCT:pass control time; SRF: shooting with the right foot; SLF: soothing with the left foot; STRF: shooting time with the right foot; STLF: shooting time with the left foot

Shooting time with the right foot. The time taken to shoot with the right foot decreased significantly for the experimental group, from 9.254 to 8.559, a reduction of 7.51 %, while the control group remained stable. The ANOVA shows a significant effect of training ($F_{(1,34)} = 13.020$, $p < 0.001$) and a significant interaction ($F_{(1,34)} = 6.184$, $p = 0.018$). Post hoc tests confirm that this reduction is significant for the experimental group ($p_{bonf} < 0.001$).

Shooting time with left foot. Performance in terms of shooting time with the left foot also showed a decrease for the experimental group, from 9.132 to 8.921, a reduction of 2.31 %. However, the effects of training and the interaction between training and groups were not significant ($F_{(1,34)} = 0.591$, $p = 0.447$, and $F_{(1,34)} = 0.527$, $p = 0.473$ respectively). Post-hoc tests show that the decrease is not significant ($p_{bonf} = 1.000$), although performance did decrease slightly for the experimental group.

The overall results of the study show that the training significantly improved both the technical skills and physical performance of the young footballers in the experimental group, compared with the control group. Notable improvements were observed in the number of passes, shooting accuracy with both feet, as well as significant reductions in pass control time and shooting time with the right foot. In terms of physical performance, significant improvements were observed in maximum aerobic speed (VMA), speed over 10 and 20 meters, angular velocity over 20 meters, as well as in squat jump (SJ) and countermovement jump (CMJ) abilities.

The results of statistical tests, including repeated measures ANOVA and Bonferroni post hoc tests, supported by percentages of change, confirm the effectiveness of the training methods used to optimize technical and athletic performance. However, the differences observed between groups for certain variables, such as speed and CMJ jumping ability, suggest that specific, targeted training approaches may be required to maximize gains in different areas of performance. These findings highlight the importance of tailored training strategies to improve both technical skills and physical abilities in the context of soccer.

Discussion

To the best of our knowledge, this is the first study to compare the effects of reduced games with position (RGP) versus traditional training applied during the competition period on the physical and technical qualities of players in training. The initial hypothesis was that RGP, with characteristics and rules similar to those of competition, would provide strong evidence supporting the effectiveness of reduced games with position (RGP) in improving the physical and technical performance of young soccer players compared to traditional training methods. RGP offer a more integrated and realistic approach, improving various performance parameters more effectively (Sarmento, Clemente et al., 2018; Olthof, Frencken, & Lemmink, 2015).

The results of the study showed that there were significant differences in the pre-test and post-test for the experimental group using the reduced position sets. These results indicate that several factors influenced the improvement in subject performance for the experimental group at posttest. The factors influencing the improvement in player performance were the implementation of training sessions over 12 weeks and the process of training in the reduced position game throughout the experimental period.

The study showed that 12 weeks of training based on reduced games with position at maximum intensity significantly improved all the physical performance characteristics tested ($p < 0.05$). RGP, due to their high intensity and short recovery periods, also promote speed endurance. This translate into a better ability to maintain

high speed over extended periods. Akdoğan, Yılmaz, Köklü, Alemdaroğlu, and Cerrah (2021) found that RGP improve speed endurance, and more recent studies confirm this observation, indicating a better ability of players to repeat intense efforts (Castillo et al., 2021). The 10 m and 20 m sprint results are in line with those of Rebelo, Silva, Rago, Barreira, and Krustrup (2016), who showed that regular RGP sessions increase players' maximum speed through frequent repetitions of short sprints. Similarly, more recent studies confirm these findings, indicating a significant improvement in maximum speed after prolonged periods of RGP (Hammami, Gabbett, Slimani, & Bouhlel, 2018). The present study indicated that training based on reduced games with position also affected 20 m speed with a change of direction.

The more restricted environment and density of players force participants to react quickly to a variety of stimuli, improving their reaction speed. A study by Querido and Clemente (2020) observed that players trained with RGP showed significant improvements in acceleration compared to those trained with traditional methods. These findings are supported by recent research showing that RGP can increase reaction speed through frequent exposure to intense game situations (Bujalance-Moreno, Latorre-Román, & García-Pinillos, 2018).

RGP are known to increase exercise intensity, raising heart rate and oxygen consumption (Sarmento et al., 2018). These conditions favor the development of physical qualities such as power and explosiveness. The squat jump is an indicator of the explosive strength concentrated in the legs. RGP, because of their requirement for rapid changes of direction and short sprints, can improve lower limb strength. A study by Rebelo, Silva, Rago, Barreira, and Krustrup (2016) showed that players who regularly participated in RGP improved their squat jump (SJ) performance. More recent research corroborates these findings, indicating significant gains in explosive strength after periods of RGP training (Hammami et al., 2018). For example, the countermovement jump (CMJ), which measures elastic power and leg explosiveness using a stretch-shortening cycle, can improve CMJ performance. Springham et al. (2024) observed significant improvements in CMJ performance after regular RGP sessions. Other recent studies support these findings, showing gains in explosive power and jump height after RGP training (Bujalance-Moreno et al., 2018).

RGP significantly improved VMA (1.16 %), 10 m linear speed (4.87 % reduction), 20 m speed (2.25 % reduction), 20 m speed with change of direction (2.84 % reduction), SJ vertical jump height (3.94 % increase), and CMJ (5.96 % increase) compared with traditional training. Consequently, the results of this study reveal that RGP may be more appropriate than traditional training for improving the physical performance of young soccer players in training.

RGP have also proven effective in improving technical skills, as evidenced by the LSPT and LSST results. Frequent interaction with the ball and realistic game scenarios in RGP help players develop better ball control, passing accuracy, and shooting accuracy (Clemente & Sarmento, 2020). Our data showed that selected players increased the number of post-test passes ($p < 0.001$). Reduced play has been shown to increase the frequency of interactions with the ball, providing more opportunities to practice passing. The more restricted environment of the RGP requires greater precision and speed in passing. A study by Sarmento et al. (2018) showed that RGP significantly improve passing accuracy through the repetition and intensity of playing situations. Furthermore, recent research indicates that RGP can increase the number of successful passes due to the constant pressure exerted by opponents (Sarmento et al., 2018). Our results for this study in reduced games with position are consistent with previous studies, as players in pressing situations can move according to their positions on the pitch, which implies intelligent movement that enables them to be effective in controlling passes.

What's more, players are constantly under pressure in the RGP. Ball control, which is a key skill in passing mastery, poses many problems for young players in training, as they have to make quick decisions to pass the ball to their partner in the best possible conditions. RGP offer an ideal framework for improving initial control and ball handling. Rebelo, Silva, Rago, Barreira, and Krustrup (2016) found that players who regularly participated in RGP showed a significant improvement in ball control. Recent studies confirm these results, highlighting that RGP increase the frequency and quality of ball touches (Bujalance-Moreno et al., 2018).

As far as shooting is concerned, RGP increase the number of shooting situations due to the constant proximity of the goal. Players often have to shoot under pressure, which improves their ability to take accurate, powerful shots in matches. This confirmation is consistent with our results. Rusdiana, Rahmatillah, and Asidik (2017) found that RGP promote improved shot accuracy and power. Other recent research shows that RGP training can increase the number of shots attempted and taken in matches due to frequent opportunities to practice this technical skill (Hammami, Gabbett, Slimani, & Bouhlel, 2018).

The results indicated that the experimental group had significantly higher values than the control group. RGP offer additional advantages over traditional training, as they integrate physical and technical aspects into the game, enabling players to develop specific skills in relation to the actual game of the match while improving the tactical side (Sgrò, Bracco, Pignato, & Lipoma, 2018). What's more, the variety of RGP formats means that sessions can be tailored to players' specific needs (Halouani, Chtourou, Gabbett, Chaouachi, & Chamari, 2014).

This study has certain limitations. It involved two teams of 20 players (experimental team and control team), which constitutes a small sample size. In addition, the level of the players could influence the results of the study. Furthermore, the assessment of off-game performance and the impact of the game context in terms of field size, number of players, and specific rules applied (Santos et al., 2018; Clemente et al., 2023) could limit the results obtained. Secondly, it is important to note that our study was conducted in a single club. Consequently, the results should be interpreted with caution, as they may not apply to all clubs in Morocco. Future research should include larger samples involving multiple clubs to enhance the generalizability of results and reduce specific biases related to the skill level of a single group of players. Additionally, it would be pertinent to diversify participant profiles by including varying levels of skill and experience, to explore the impact of small-sided games (SSGs) across a wider range of players.

It would also be useful to conduct longitudinal studies that allow the observation of SSG effects over extended periods. By tracking players over multiple seasons, researchers

could assess the long-term effects of SSGs on players' technical, physical, and tactical performance compared to traditional training.

Furthermore, an in-depth analysis of contextual variables, such as field size, the number of players, and specific rules, could provide a better understanding of their influence on SSG outcomes. Future research could therefore explore different SSG formats, adjusting these parameters to optimize training according to specific objectives (e.g., developing game vision, pressing ability, or endurance).

Finally, to enrich the understanding of SSG impacts, it would be beneficial to integrate more precise measurement tools, such as GPS technology to track players' movements, or video analysis to examine tactical behaviors. These methods could provide more detailed quantitative and qualitative data on observed improvements, allowing for more tailored adaptation of SSGs to the individual needs of players and the specific characteristics of each game context.

Conclusions

This study shows that twelve weeks of training with reduced games with position during the competition period improves physical and technical qualities. Indeed, our results indicate that a twelve-week training program with 3 weekly sessions of reduced games with position aimed at improving endurance, muscular strength and power, linear sprinting and speed with change of direction, as well as specific technical skills, ball control, passing and shooting, led to significant improvements in young footballers in training. Our results may help soccer coaches to better select the most effective training methods during the competition period.

Conflict of Interest

The authors state that they have no competing interests.

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Порівняльний аналіз впливу редукованих позиційних ігор та традиційного тренування на показники фізичної та технічної результативності юних футболістів у процесі підготовки

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

Реферат. Стаття: 10 с., 2 табл., 3 рис., 33 джерела.

Історія питання. Впровадження редукованих позиційних ігор як методу тренування в сучасному футболі є важливим визначальним чинником вдосконалення та розвитку навичок юних футболістів у процесі підготовки.

Мета дослідження. Метою дослідження було визначити вплив 12-тижневого періоду застосування редукованих позиційних ігор на показники фізичної та технічної результативності юних футболістів під час тренувань.

Матеріали та методи. У дослідженні взяли участь 40 футболістів чоловічої статі, які тренуються в клубі CFC, що представляє національний чемпіонат Марокко U17. Відповідно до клубної приналежності, гравців було розподілено на експериментальну групу, в якій застосовувалася практика редукованих позиційних ігор, та контрольну групу, яка займалася в рамках традиційних тренувань. Обидві команди брали участь у тренувальних заняттях тричі на тиждень протягом 12 тижнів. Кожне заняття тривало 90 хвилин. Перед початком і після завершення курсу обидві групи виконували тести з фізичної підготовки (Yo-Yo інтервальний тест на визначення рівня загальної фізичної витривалості, лінійний спринт на 10 м, 20 м і 20 м зі зміною напрямку, стрибок із положення присіду, вертикальний стрибок із контррухом), а також тести з оцінки рівня технічної підготовки (LSPT — The Loughborough Soccer Passing Test, Лафборський тест на визначення точності пасів; LSST — The Loughborough Soccer Shooting Test, Лафборський тест на визначення точності ударів), під час яких оцінювалися всі показники, досягнуті учасниками обох груп. З метою кількісної оцінки результатів використовувалися наступні програми: OptoJump (оптична система контролю та аналізу кінематичних характеристик локомоторних рухів спортсменів), додаток My Jump (технологія вимірювання результативності стрибків) та матриця контролю технічних елементів.

Результати. Результати дослідження виявили значне покращення показників максимальної аеробної швидкості (МАШ) ($p < 0,001$; $n^2 = 0,017$); спринті на 10 м ($p < 0,001$; $n^2 = 0,102$), спринті на 20 м ($p = 0,002$; $n^2 = 0,022$), спринті на 20 м ($p < 0,001$; $n^2 = 0,022$), спринті на 20 м зі зміною напрямку ($p < 0,001$; $n^2 = 0,087$), а також збільшення висоти стрибків із положення присіду ($p < 0,001$; $n^2 = 0,012$) і вертикальних стрибків із контррухом ($p < 0,001$; $n^2 = -0,016$). Порівняно з результатами Лафборського тесту на визначення точності пасів, в експериментальній групі спостерігалося збільшення кількості передач м'яча ($p < 0,001$; $n^2 = 0,175$) і суттєве поліпшення показників контролю пасів ($p < 0,001$; $n^2 = 0,131$). За результатами Лафборського тесту на визначення точності ударів, встановлено значне підвищення результативності ударів ($p = 0,001$; n^2 (права нога) = 0,045; n^2 (ліва нога) = 0,049) та зменшення часу виконання ударів ($p = 0,001$; n^2 (права нога) = 0,045, n^2 (ліва нога) = 0,005). Post-hoc тести продемонстрували, що тренування із застосуванням редукованих позиційних ігор призвело до суттєвого покращення показників у виконанні стрибків із положення присіду, вертикальних стрибків із контррухом, спринті на 10 м, спринті на 20 м, спринті на 20 м зі зміною напрямку, а також результатів проведення LSPT та LSST.

Висновки. Отримані дані вказують на значне поліпшення показників фізичної та технічної результативності юних футболістів у процесі підготовки за 12-тижневою програмою тренувань на основі редукованих позиційних ігор, що передбачало проведення 3-х тренувальних занять на тиждень. Таким чином, тренерському складу та тренерам з фізичної підготовки рекомендується включити тренувальні заняття на основі редукованих позиційних ігор до програми річного циклу підготовки команди.

Ключові слова: тренування, редуковані позиційні ігри, юні футболісти, фізичний, технічний.

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Original Scientific Article

Analyzing the Impact of an 8-Week Structured Physical Activity Program on Health-Related Fitness in Bhutanese Seventh-Grade Students

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

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Abstract

Objectives. This study aimed to evaluate the impact of an 8-week physical activity program (PAP) on health-related fitness (HRF) components of seventh graders in Bhutan. Its emphasis areas included assessing the program's effects on cardiorespiratory endurance, muscular strength, muscular endurance, flexibility, and body composition.

Materials and methods. Sixty-two students were allocated into two groups using simple random sampling: a control group (n = 31) following the standard physical education curriculum and an experimental group (n = 31) participating in the PAP utilizing the FITT (frequency, intensity, time, and type) principle. Fitness Gram assessments were used to measure HRF before implementing the intervention. Independent t-tests were used to compare results between groups, whereas paired t-tests were used to compare pre-test and post-test scores within groups.

Results. All HRF components demonstrated notable improvements in the experimental group. Cardiorespiratory endurance increased from a mean of 23.23 to 30.57 ($p < 0.05$), muscular strength – from 7.47 to 12.37 ($p < 0.05$), muscular endurance – from a mean of 10.10 to 16.40 ($p < 0.05$), and flexibility – from 27.98 to 29.85 ($p < 0.05$). It was additionally observed an improvement in body composition, with a notable decline in BMI. Conversely, the control group showed a less significant decrease in flexibility and BMI, while demonstrating marked enhancements in cardiorespiratory endurance, muscular strength, and muscular endurance.

Conclusions. The study indicates that the organized PAP was more effective than the standard physical education curriculum in improving HRF components. These findings suggest that the implementation of structured PA programs using the FITT principles can lead to enhanced physical fitness and health-related outcomes among children and young people.

Keywords: Bhutanese student, health-related fitness, physical activity program.

Introduction

The lifestyle changes that are caused by the COVID-19 pandemic have led to the adoption of physical inactivity which became a serious global threat affecting people of all ages. As a result, the decline in health-related fitness (HRF) among children and adolescents should be of particular concern because it increases the likelihood of cardiovascular disease, metabolic syndrome, obesity, and deterioration in life quality (Ye et al., 2018). An alarming trend that has emerged during the 21st century is the rising prevalence of obesity in children and adolescents (Gjonbalaj et al., 2022). Noteworthy is also the fact that 75-81 % of teenagers between 11-17 years from all over the world do not meet the recommended levels of physical activity (PA) (WHO, 2019), which indicates a monotonous trend of inactivity that needs quick intervention.

According to Carlson et al. (2015) and Tremblay et al. (2017), children's excessive screen time and a lack of outdoor activities in the modern day have made them physically inactive. This increases the chances of becoming overweight and less physically active because children find less time for PA at school (Himmelstein et al., 2017).

People who lead sedentary lives also prove burdensome to society due to the costs of healthcare, which represent 1 % to 3 % of the national expenditures (World Health Organization, 2019). This problem is also associated with an increase in non-communicable diseases (NCDs) including diabetes, obesity, and even cardiovascular disease (Bull et al., 2020).

In Bhutan, there is a noticeable increase in physical inactivity and sedentary behavior among adolescents, with

29.12 % reported as physically inactive according to the Global School-Based Health Survey. This decline in HRF corresponds with a rising burden of NCDs, which accounted for 69 % of deaths in 2014 and rose to 71 % by 2019 (Dendup et al., 2020). Conditions such as obesity, diabetes, and heart disease are becoming more prevalent among students (Tamang et al., 2022). The WHO STEPS survey identifies inactivity as a key risk factor for the increasing incidence of NCDs in Bhutan (World Health Organization, 2021).

The physical education curriculum in Bhutan does point out the merits of PA, however, it is rather vague about specific regimes to promote fitness levels (Gyaltshen, 2023). Also, there is a gap for such studies that would connect PA with HRF among children and adolescents based on the FITT principles (frequency, intensity, time, type).

Physical activity is defined as any movement of body muscles that results in energy expenditure greater than resting levels (Almnifi et al., 2023; Bearne, 2023; Kandola & Bann, 2021). Key factors in assessing physical activity include mode, frequency, intensity, duration, and context (Thivel et al., 2018). The NCDs view PA as a vital preventative strategy (Sánchez-Roa et al., 2024).

Engaging in regular PA improves oxygen transport, aerobic capacity, body composition, and muscular strength and endurance (Cooper Institute, 2017). It also strengthens core muscles and bones, helps maintain or reduce body mass, and reduces the risk of chronic conditions like CVD and diabetes, enhancing life expectancy (Amal et al., 2024). Additionally, PA positively impacts mental health by decreasing depression and anxiety while improving cognition (Melnyk et al., 2020; Northey et al., 2018; Rebar et al., 2015). It reduces the likelihood of developing chronic conditions such as CVD and metabolic syndrome (Swift et al., 2014). Pocaan (2024) makes an argument that is considered one of the key aspects that influence overall health.

HRF benefits from regular PA, which encompasses five components: 1) cardiovascular endurance (CRE), 2) muscular strength (MS), 3) muscular endurance (ME), 4) flexibility, and 5) body composition (BC) (American College of Sports Medicine, 2013; Britton et al., 2020). CRE indicates a person's ability to exert effort in cardiovascular and respiratory function (Britton et al., 2020), while MS measures the maximum force a muscle can generate (Smith et al., 2014). ME reflects the ability to sustain muscle strength over time (Smith et al., 2014), and flexibility pertains to the range of motion in joints (Knudson, 2018). Body composition involves the various components that make up the body (American College of Sports Medicine, 2013).

Research indicates that these five components are critical standards for assessing training effectiveness, enabling a comprehensive evaluation of HRF. This broader assessment provides a solid foundation for understanding an individual's fitness and health. Additionally, studies show that traditional gender role stereotypes affect HRF rates, with males generally outperforming females in all components except flexibility (Santos et al., 2014). However, the core elements of the HRF construct are consistent across genders.

The literature review revealed a gap in research on the impact of PAP on the HRF of adolescents in Bhutan, particularly concerning Bhutanese anthropology. While international studies show that physical inactivity harms HRF, most research has focused on developed countries, highlighting the need for region-specific studies.

This study evaluates the impact of PAP on HRF among Bhutanese students, focusing on CRE, MS, ME, flexibility, and BC. It is based on two hypotheses: that PAP will significantly improve HRF within the same group over time and that there will be notable HRF score differences between the two groups after a post-test. The findings aim to enhance scholarly literature and assist educators and decision-makers in promoting youth health and fitness in Bhutan.

Materials and Methods

Study Participants

The study participants were a total of 402 students of Pema Gatshel Middle Secondary School in Bhutan. The sample size n = 62 was computed using the G*Power program, version 3.1.9.7, and utilized an effect size of 0.8, p = 0.05, and test power of 95 % (1-β = 0.95). In this regard, it was determined that the sampling size was 28 participants per group. However, to prevent cases of potential dropouts during data collection, a further 10 % (3 participants per group) was included. As such, the 62 participants were divided, 31 into the experimental group and 31 in the control group. The inclusion and exclusion criteria were as follows:

Inclusion Criteria

1. Bhutanese students enrolled in an educational institution in Bhutan.
2. Aged 13 to 17 years.
3. Not involved in other research studies.
4. No history of chronic diseases (cardiovascular, diabetes, asthma, neurological conditions, hypertension).
5. Confirmed participation in the program.
6. Previous experience in physical activities without limitations.

Exclusion Criteria

1. History of chronic diseases.
2. Disabilities hindering participation in physical activities.
3. Aged under 13 or over 18 years.
4. Currently involved in other research studies.
5. No consent from a Legally Authorized Representative (LAR).

Due to one participant from the experimental group withdrawing and another from the control group being lost to follow-up, the final analysis included 60 participants: 30 from the experimental group and 30 from the control group as shown in the demographic characteristics in Table 1 and the outline of the PAP and HRF testing schedule in Figure 1.

Study Design

This study employed a two-group quasi-experimental design consisting of an experimental group (EG) and a control group (CG). The structure of the experimental plan is outlined as follows:

EG (n = 31): $O_1 \rightarrow X_1 \rightarrow O_2$

CG (n = 31): $O_3 \rightarrow X_2 \rightarrow O_4$

where X_1 represents the implementation of a PAP based on the FITT (frequency, intensity, time, and type) principle, developed by the research team.

X_2 represents the standard physical education class based on the prescribed PE curriculum in Bhutan.

O_1 and O_3 indicate pre-experiment HRF assessments for the experimental and control groups.

O_2 and O_4 represent post-experiment HRF assessments conducted after eight weeks of the intervention.

The research began with the administration of the HRF pre-test using the FitnessGram test batteries for both the experimental and control groups. The experimental group then participated in an 8-week structured PAP with two 60-minute sessions per week, while the control group followed Bhutan's Physical Education curriculum with one 40-minute session per week. After the intervention, both groups were retested to assess their HRF levels, and the mean scores were calculated.

Research Instrument

The research instrument for this study consists of adapted physical fitness test batteries from FitnessGram, developed by the Cooper Institute (Table 3). While various tools assess HRF globally, this study used FitnessGram because it includes a comprehensive set of age- and sex-specific tests that align with criterion-referenced health standards for children and youth (Cooper Institute, 2017).

Table 1. Demographic characteristics of participants (n = 60)

Variables	Experimental Group (n = 30)		Control Group (n = 30)	
	n	%	n	%
Sex				
Male	13	43.33	13	43.33
Female	17	56.67	17	56.67
Age (year)				
13	12	40.00	0	0.00
14	14	46.67	20	66.67
15	3	10.00	6	20.00
16	0	0.00	4	13.33
17	1	3.33	0	0.00

Adaptations were made from credible sources to ensure the instrument's validity and appropriateness for this research.

Human Research Ethics

This study received ethical approval from the research ethics review committee of Naresuan University, under

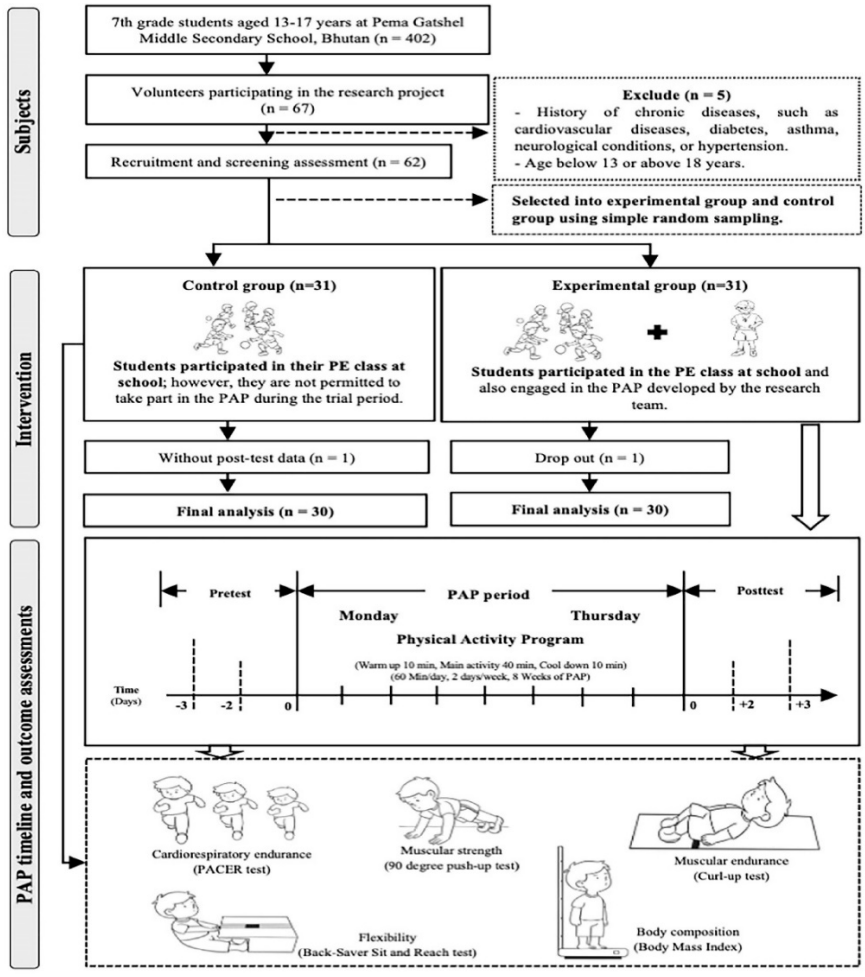

Fig. 1. Outline of PAP and HRF testing schedule

Table 2. Summary of treatment program design for week 1-8

Week	Experimental group (PAP)		Control group (PE)
	Activity	Duration	Activity Duration
1	Yoga for Flexibility.	60’	A 40-minute Physical Education (PE) class per week, with activities aligned to the prescribed Physical Education curriculum in Bhutan
	Partner Stretching.	60’	
2	Outdoor Stretching Adventure.	60’	
	Resistance Band Exercises.	60’	
3	Yoga for Strength.	60’	
	Flexibility Circuit Training.	60’	
4	Bodyweight Circuit.	60’	
	Resistance Band Workout.	60’	
5	Calisthenics Routine.	60’	
	Partner Squat.	60’	
6	Circuit Training.	60’	
	Aerobic Dance.	60’	
7	Run for Distance.	60’	
	Uphill Relay.	60’	
8	Soccer Drills.	60’	
	Team Sports.	60’	

Table 3. Health-Related Fitness Test Battery

Components	Test battery	Assessment
Cardiorespiratory Endurance (CRE)	Progressive Aerobic Cardiovascular Run (PACER)	Maximum aerobic fitness of students
Muscular Strength (MS)	90-degree push-up	Upper body strength and endurance
Muscular Endurance (ME)	Curl up	Abdominal muscle endurance
Flexibility	Back-Saver Sit and Reach	Flexibility of left and right legs
Body Composition (BC)	Body Mass Index (BMI)	Body composition

the approval code COA No. 309/2024 NU-IRB No. P1-0014/2567. Informed written consent was obtained from each volunteer before participation in the study.

Statistical analysis

This study analyzed data using descriptive and inferential statistics, specifically focusing on HRF mean scores. Descriptive statistics were used to present the mean HRF scores, providing an overview of data distribution and key characteristics (Wibowo et al., 2024). The Shapiro-Wilk test assessed normality before the experiment. Within-group comparisons of pre-test and post-experiment HRF scores used paired t-tests, while independent t-tests were applied for between-group comparisons after the 8-week intervention. Statistical significance was set at p = 0.05, with all analyses conducted using SPSS software.

Results

This study involved 60 seventh-grade students from Pema Gatshel Middle Secondary School in Bhutan, divided into an experimental group and a control group, each with 30 students (13 males and 17 females, average age 14 ± 0.9 years). It investigates the effects of a structured PAP on HRF across five components: CRE, MS, ME, flexibility, and BC, comparing the outcomes with those of standard PE.

Table 4 compares the mean scores for HRF components in the experimental group (n = 30) and control group (n = 30) before and after the intervention. The paired sample t-test showed significant differences (p = 0.05), indicating that the intervention improved all fitness components. In the context of CRE, the mean showed an increase of 7.34 (p = 0.00). MS rose by 4.90 (p = 0.00), and ME improved by 6.30 (p = 0.00). Flexibility showed a slight increase of 1.87 (p = 0.00), while BC experienced a decrease of 1.49 (p = 0.00).

The control group significantly improved several fitness components. CRE increased by 1.93 (p = 0.00), and MS rose by 1.70 (p = 0.00). The ME showed an improvement of 1.47 (p = 0.03), while flexibility remained unchanged (p = 0.14).

Table 4. Comparison of Pretest and Posttest Health-Related Fitness Scores in the experimental group and control group

Components	Group	Test	n	Mean	SD	t-value	Sig.
CRE	EXP	Pre	30	23.23	10.42	-6.23	0.00*
		Post	30	30.57	13.98		
	CON	Pre	30	21.30	9.91	-8.81	0.00*
		Post	30	23.23	10.64		
MS	EXP	Pre	30	7.47	4.34	-17.97	0.00*
		Post	30	12.37	4.98		
	CON	Pre	30	7.30	5.39	-5.16	0.00*
		Post	30	9.00	5.48		
ME	EXP	Pre	30	10.10	7.48	-10.10	0.00*
		Post	30	16.40	8.48		
	CON	Pre	30	10.00	6.03	-2.29	0.03*
		Post	30	11.47	7.11		
Flexibility	EXP	Pre	30	27.98	5.82	-3.33	0.00*
		Post	30	29.85	5.05		
	CON	Pre	30	24.43	5.30	-1.54	0.14
		Post	30	25.86	5.49		
BC	EXP	Pre	30	22.45	3.56	14.12	0.00*
		Post	30	20.96	3.54		
	CON	Pre	30	22.46	2.86	6.48	0.00*
		Post	30	21.67	2.77		

*Significant p = 0.05, CRE = cardiorespiratory endurance, MS = muscular strength, ME = muscular endurance, BC = body composition, EXP = experimental group, CON = control group.

Table 5. Comparison of Posttest Health-Related Fitness Scores between experimental group and control group (n = 60)

Components	Group	n	Mean	SD	t-value	Sig.
CRE	EXP	30	30.57	13.98	2.29	0.03*
	CON	30	23.23	10.64		
MS	EXP	30	12.37	4.98	2.49	0.02*
	CON	30	9.00	5.48		
ME	EXP	30	16.40	8.48	2.44	0.02*
	CON	30	11.47	7.11		
Flexibility	EXP	30	29.85	5.05	2.93	0.01*
	CON	30	25.86	5.49		
BC	EXP	30	20.96	3.54	-0.87	0.39
	CON	30	21.67	2.77		

*Significant $p < 0.05$, CRE = cardiorespiratory endurance, MS = muscular strength, ME = muscular endurance, BC = body composition, EXP = experimental group, CON = control group.

BC also improved, with a decrease of 0.79 in the mean ($p = 0.00$). Overall, there were notable improvements in endurance, strength, and body composition.

Table 5 indicates post-test analysis comparing the experimental group (EXP) and the control group (CON) reveals significant improvements in various fitness components. The EXP achieved a mean score in CRE that was higher than the CON by a mean difference of 7.34 ($p = 0.03$). In MS, EXP scored higher by a mean difference of 3.37 ($p = 0.02$). The EXP also recorded a higher mean in ME, with a mean difference of 4.93 compared to the CON ($p = 0.02$). Flexibility improved as well, with EXP scoring higher than CON by a mean difference of 3.99 ($p = 0.01$). Although BMI did not show a significant difference ($p = 0.39$), the EXP had a lower mean BMI, indicating a positive trend in body composition.

Discussion

The PAP was more effective at improving HRF than the standard PE program. Incorporating FITT principles, the PAP successfully enhanced students' fitness levels by targeting all HRF components. Significant improvements were observed after the 8-week program.

Figure 2 indicates that the results showed a significant improvement in post-test scores for CRE in the experimental group compared to the control group, which also showed some improvement but to a lesser extent. Participants in the experimental group had a mean difference of 7.34, demonstrating the benefits of organized PAP that included running, jogging, and movement exercises. Over the 8 weeks, increasing task difficulty enhanced oxygen uptake and cardiovascular efficiency. The FITT principles were applied to carefully monitor and adjust exercise frequency and intensity, ensuring students faced appropriate challenges. In contrast, the control group, following a standard PE curriculum, experienced limited improvements in CRE due to fewer aerobic workouts. This finding aligns with research by Song et al. (2021), which noted that targeted cardiovascular exercise programs can enhance strength among schoolchildren. The principle of specificity was crucial, as the PAP focused on exercises designed to boost cardiovascular efficiency, unlike standard PE programs.

Additionally, the experimental group exhibited a significant increase in muscular strength with a mean difference of 4.90. This improvement resulted from incorporating resistance exercises like push-ups and bodyweight training, which effectively overloaded the muscles within each student's physical limits. In contrast,

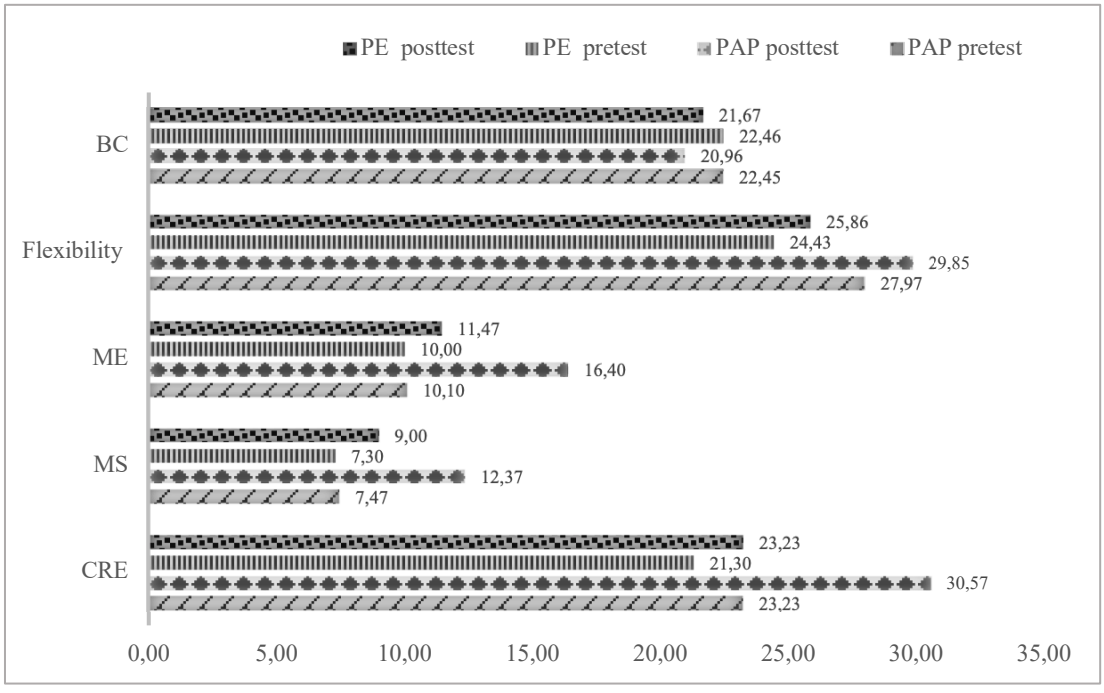

Fig. 2. Changes in HRF after 8 weeks of the intervention period

the control group experienced only a minimal increase in strength, with a mean difference of 1.70, likely due to the absence of systematic muscle toning activities in the standard PE curriculum. The overload principle was key to the PAP, enabling students to progressively enhance their strength. Gonçalves et al. (2019) highlighted that structured physical activity, including resistance training, significantly improves basic motor skills in schoolchildren. These findings suggest that targeted resistance exercises should be integrated into the PAP, as they are often overlooked in standard PE programs.

Similarly, the experimental group showed a significant improvement in muscular endurance, with a mean difference of 6.30. This increase reflects a better ability to sustain muscle contractions. The repetitive exercises in the PAP focused on low resistance and high repetitions, including bodyweight squats and planks. In contrast, the control group had a mean difference of 1.47, though this change was less significant due to a lack of structured endurance exercises in their PE sessions. The success of the PAP was largely due to its progressive design, enabling students to gradually enhance their endurance levels. These findings align with research by Cvejic and Ostojić (2018), which showed that structured PAPs effectively improve muscular endurance in school-aged children. The program adhered to FITT principles, focusing on the frequency and intensity of workouts, resulting in greater improvements than standard PE curricula.

Moreover, the experimental group demonstrated better flexibility than the control group, with a mean score difference of 1.87. This improvement is likely due to the targeted stretching exercise and dynamic and static stretching included in the PAP during warm-up and cool-down sessions, which focused on major muscle groups and joints. In contrast, the control group, following the standard PE curriculum, saw a modest change with a mean score difference of 1.43 due to limited flexibility training. Flexibility is essential for injury prevention and performance enhancement, yet it often receives insufficient attention in fitness programs. The PAP's targeted approach contrasts with the broader focus of typical PE classes. Supporting this, Ługowska et al. (2023) found that targeted stretching significantly improves adolescents' flexibility.

With the changes in body composition, the experimental group experienced a significant improvement with a mean score difference of 1.49. Such an enhancement is seen as a result of calorie-burning exercises incorporated in the PAP intending to increase the students' lean muscles. Conversely, the control group had a slight decrease in body mass index from a mean score difference of 0.79, which was sufficient to emphasize the non-physical impact of standard PE lessons on body composition. This is consistent with the findings of Swift et al. (2014), who found that supervised PAPs incorporating aerobic and resistance exercises were superior in improving body composition than general activity programs. Overload was a relevant concept in the PAP, as exercising with high- and low-intensity aerobic exercise with resistance training worked together to keep a calorie deficit while encouraging muscle expansion, thus improving overall body composition. It is acknowledged that to improve body composition, the two interventions of aerobic and resistance training should be encouraged and included in the PAPs, a prediction that is sometimes neglected in regular PE classes.

The study's results indicate that the PAP, designed with the FITT principles, was more effective than traditional PE in improving HRF among seventh-grade students. The PAP led to significant gains in cardiorespiratory endurance, muscular strength, muscular endurance, flexibility, and body composition through its organized approach with targeted exercises.

By applying the FITT principles, the program provided an optimal stimulus for enhancing fitness. These findings suggest that implementing structured PAPs in schools can lead to better fitness outcomes for children, promoting their overall health and well-being. Moreover, they highlight the inadequacies of the traditional PE curriculum, suggesting a need for a more integrated approach to PE.

Conclusions

The current study showed that with proper planning and application of the FITT principles, a PAP can significantly improve the HRF levels of school-aged children. The findings support implementing structured PAPs in schools to address all HRF components, helping children achieve lasting fitness and health benefits. Additionally, the study highlights the need for specific exercises, progressive overload, and appropriate intensities in PAP design to foster positive changes in fitness. These programs aim to combat the growing concerns of physical inactivity and its health consequences among children.

Recommendations

Recommendations for the Implications of the Study:

1. The study's findings can guide schools in Bhutan to adopt similar PAPs.
2. A structured PAP based on FITT principles can offer students a more effective fitness experience than traditional PE classes.

Recommendations for Further Research:

1. Future research should examine the long-term effects of PAPs on student fitness and health outcomes over extended periods.
2. Studies should also consider integrating nutritional guidance with PAPs to improve body composition.
3. Expanding research to include larger, diverse populations in Bhutan would provide valuable insights for policymakers in developing tailored health promotion programs.

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Conflict of interest

The authors declare that there is no conflict of interest.

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Аналіз впливу 8-тижневої структурованої програми фізичної активності на показники оздоровчого фітнесу учнів сьомих класів у Бутані

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

Реферат. Стаття: 9 с., 5 табл., 2 рис., 37 джерел.

Мета дослідження. Мета цього дослідження полягала в проведенні аналізу впливу 8-тижневої програми фізичної активності (ПФА) на компоненти оздоровчого фітнесу (ОФ) учнів сьомих класів у Бутані. Основні напрямки дослідження включали оцінку впливу програми на показники кардіореспіраторної витривалості, м'язової сили, м'язової витривалості, гнучкості і композиції тіла.

Матеріали та методи. За методом простої випадкової вибірки 62 студенти було розподілено на дві групи: контрольну (n = 31), яка займалася за стандартною програмою фізичного виховання, та експериментальну (n = 31), яка брала участь у ПФА із застосуванням принципу FITT ("frequency", "intensity", "time", and "type" — частота, інтенсивність, час і тип). Перед впровадженням інтервенції з метою вимірювання показників ОФ використовували методику Fitness Gram. Для проведення порівняльного аналізу результатів між групами використовували t-критерії для незалежних вибірок, а для зіставлення результатів на перед- та післятестовому етапах дослідження — t-критерії для парних вибірок в межах зазначених груп.

Результати. В експериментальній групі помітно покращилися всі компоненти ОФ. Кардіореспіраторна витривалість зросла в середньому з 23,23 до 30,57 ($p < 0,05$), м'язова сила — з 7,47 до 12,37 ($p < 0,05$), м'язова витривалість — з 10,10 до 16,40 ($p < 0,05$), а гнучкість — з 27,98 до 29,85 ($p < 0,05$). Крім того, спостерігалося поліпшення показників композиції тіла, з істотним зниженням індексу маси тіла (ІМТ). Натомість у контрольній групі спостерігалося менш значне зниження показників гнучкості та ІМТ, водночас відзначалося виражене підвищення рівнів кардіореспіраторної витривалості, м'язової сили та м'язової витривалості.

Висновки. Дослідження вказує на ефективність застосування організованої ПФА щодо покращення компонентів ОФ порівняно зі стандартною навчальною програмою з фізичного виховання. Отримані дані свідчать про доцільність впровадження структурованих програм фізичної активності із застосуванням принципів FITT для підвищення показників фізичної підготовленості та оздоровчих результатів серед дітей та молоді.

Ключові слова: бутанський учень, оздоровчий фітнес, програма фізичної активності.

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Unravelling Students' Attitudes Toward Lifelong Exercise

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

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Abstract

Background. A central purpose of learning in physical education (PE) is to facilitate students' physical development and competence that determine lifelong engagement in exercise. Therefore, exploring and understanding students' attitudes toward lifelong exercise contributes significantly to achieving it.

Objectives. Two studies examined students' attitudes toward lifelong exercise. The first study focused on using social and personal variables as predictors. The second study involved a repeated measures design to determine if there were differences in attitudes as students progressed to the next grade and between schools. Additionally, the study aimed to investigate whether there were variations in attitudes based on the students' physical activity levels.

Materials and methods. In the first study, 752 students of the 7th and 10th grades participated, representing 47 classes from 14 schools. Then, after conducting a repeated measures analysis one academic year later, from the initial sample, 460 students formed two cohorts, comprising Grades 7–8 and 10–11. All factors were internally consistent and well-defined by the variables. The first study used hierarchical linear regression to ascertain whether social and personal variables could be identified as predictors of students' attitudes toward lifelong exercise. The second study used a mixed ANOVA to assess differences in students' attitudes, measuring at two time points and between schools. Furthermore, a one-way ANOVA was performed to determine whether there were variations depending on students' physical activity level.

Results. According to the findings of this study, personal variables eliminated the significance of social variables, with task orientation having the highest beta (.33). The results also revealed a significant interaction between measurements in Grades 7 and 8, as well as between schools. Moderately and highly active students had more positive attitudes than sedentary students in both cohorts.

Conclusions. Task orientation and personal progress should be emphasized to increase students' motivation. Nevertheless, a task-supportive climate could improve their intrinsic motivation for lifelong exercise.

Keywords: attitudes, predicting, lifelong exercise, social variables, personal variables.

Introduction

In the last 20 years, the need to adopt lifelong exercise as a central goal for Physical Education (PE) has been crystallized (Wang & Chen, 2019). According to many countries' curricula, PE aims to develop students' knowledge, skills, and understanding to promote physical capacity and competence to maintain a lifelong engagement in PA and sports (MacNamara et al., 2011). This goal suggests that PE should emphasize physical activity (PA) promotion in and out of school (Wang & Chen, 2019). Physical education (PE) can significantly contribute to achieving these objectives by developing successful learners and competent individuals with the knowledge, skills, and understanding to participate effectively and enjoy physical activities now and in the future (MacNamara et al., 2011). The World Health Organization specifically pinpointed schools as a key environment for promoting physical activity among children and teenagers, suggesting that schools should introduce opportunities and programs for physical activity and provide safe and suitable spaces that encourage participation in physical activity (WHO, 2021). Meanwhile, participation in physical activity is influenced by numerous factors to different extents, while behavioral changes can be attributed to both personal and social factors (Hu et al., 2021). Thus, while the value of lifelong exercise has been scientifically documented and accepted among physical education teachers (Polet et al., 2019), additional research is necessary to understand the factors that predict students' positive attitudes toward exercise and sports (Gut et al., 2020).

Students' attitude toward lifelong exercise reflects their tendency to act positively or negatively toward that concept

of interest (Fishbein & Ajzen, 2010). Its significance lies in correlating considerably with intention (Ajzen, 2005). The study of attitudes in the literature in recent years is explored through the theories of Fishbein and Ajzen (Atzen, 1985, 1988, 1993; Atzen & Fishbein, 1980) and their theoretical model that evolved with the following theories Theory of Reasoned Action (TRA), Theory of Planned Behavior and The Reasoned Action Approach (Silverman, 2017). Attitude is mainly investigated as a two-factor model, cognitive and affective (Mercier et al., 2022; Lima et al., 2018). The affective factor describes feelings related to their attitude and reflects the emotional attachment to the subject, while direct experience interactions often form it (Balga et al., 2019). On the other hand, the cognitive factor concerns beliefs (Donovan et al., 2015) and is linked to the logical evaluation of the object of an attitude, including what students know about the subject of their attitude. It includes their perceptions, thoughts, opinions, or evaluations about a topic, including perceived benefits of PE (Silverman, 2017) and positive and negative aspects (Balga et al., 2019). Additionally, motivation plays a critical role in identifying the potential of the school context to intervene and encourage young people to participate in physical activity during their free time (Polet et al., 2019) and later in life (Polet et al., 2020). Therefore, this research investigates potential social and personal variables of attitude theory and Achievement Goal Theory (AGT) concerning students' lifelong exercise. Social variables refer to motivation climate, and personal variables refer to perceived athletic competence, task and ego orientation in PE, perceived benefits of PE, and enjoyment in PE.

Social Factors

In the educational context, teachers regulate students' motivation through the motivational climate they create (Rodrigues et al., 2020). According to Achievement Goal Theory (AGT) (Nicholls 1984), the motivational climate perceived by the students refers to the environment created by what teachers say and do in the class context (Rodrigues et al., 2020), their teaching style, type of tasks, recognition of effort, feedback, and assessment procedures (Theodosiou & Papaioannou, 2006). Based on Ames (1992), two types of climates have been proposed: On one hand, a task-oriented climate perceives learning and personal progress as necessary, based on task and effort, while mistakes are crucial parts of the learning process (Rodrigues et al., 2020). Task-oriented climates are associated with enjoyment, interest, intrinsic motivation (Ferrer-Caja & Weiss, 2000; Papaioannou, 1994), and intention toward out-of-school sports participation (Rodrigues et al., 2020). On the other hand, there is an ego-oriented climate where teachers emphasize ego-referenced criteria (Rodrigues et al., 2020) and normative superiority (Theodosiou & Papaioannou, 2006). Ego-oriented climates are related to student comparison. Furthermore, students' perceptions of differential treatment and normative references are linked to unfavorable achievement outcomes (Rodrigues et al., 2020). Research shows that focusing on ego-oriented climates does not enhance student motivation or is not viewed as a desirable teaching strategy (Papaioannou, 1998), while it is negatively related to intrinsic motivation, interest, and perceived usefulness of lessons (Papaioannou, 1994).

Personal Factors

As AGT suggests, students' view of learning and the goals they choose to pursue are in an achievement setting and act as goals of action (Jaakkola et al., 2019), while individuals can demonstrate competence through two goal dimensions: Task and ego-orientated goals (Williams & Gill, 1995). Task-oriented students tend to adopt a positive, self-referenced perception of ability. Competence and subsequent satisfaction are obtained when they improve their performance, learn new skills, and do their best (Jaakkola et al., 2019; Williams & Gill, 1995). Students with a task orientation demonstrate positive or adaptive motivated behavior (Wang & Liu, 2007) and put significant effort into developing skills and self-improvement (Jakobsen, 2022). In research, holding a task-oriented goal is an essential predictor of youth sports and exercise participation (Papaioannou et al., 2006).

On the other hand, students holding an ego-oriented goal adopt a socially or normatively referenced perception of ability (Jaakkola et al., 2019) and evaluate success by comparing their ability with that of others (Jakobsen, 2022; Zourbanos et al., 2014). For instance, students feel successful when they demonstrate superior ability, outperform others (Smith et al., 2015), and are evaluated as top performers (Papaioannou, 1994), exert less effort than others while still being socially acceptable (Jaakkola et al., 2019). In addition, they are likely to demonstrate adaptive or maladaptive motivational responses depending on their level of perceived competence (Wang & Liu, 2007).

Furthermore, physical competence in PE influences students' motivation and affects students' physical performance and behavior (Kokkonen et al., 2020). It is among the most relevant contributors to PA during adolescence (Kokkonen et al., 2020), with physical educators playing an essential role in students' perceptions of physical competence (Wallhead & Buckworth, 2004). When students think they have demonstrated competence, they experience success (Williams & Gill, 1995), while students who perceive themselves as more competent in PE participate more in out-of-school PA (Wallhead & Buckworth, 2004).

Another vital mediator in PE that is positively and invariably associated with students' PA and out-of-school PA is enjoyment (Jaakkola et al., 2019; Huhtiniemi et al., 2019). The concept of enjoyment reflects an affective construct connected to enthusiasm, competence, and excitement for an activity like school PE (Jaakkola et al., 2019). It expresses the emotions of happiness, liking, pleasure, and fun (Jaakkola et al., 2019), while it implies that students participate in physical education when they are happy and enjoy it (Zhou & Wang, 2019).

Furthermore, students' perceived benefits of PE are a crucial factor that correlates with PA among youths and is significantly associated with 60 minutes or more of PA per day (Roth et al., 2019). They relate to the actions to be taken and explain the positive benefits expected from participating in PE (Standage et al., 2003b). Students willingly participate, even though the various actions may not be perceived as inherently pleasurable (Standage et al., 2003b). Students tend to emphasize the perceived benefits of PA in PE, including enjoyment, social advantages (like spending time with friends), psychological benefits, and improved athletic performance (Lyu & Gill, 2011).

Moreover, research indicates that participation in organized sports is a strong predictor of future physical activity (Kjønniksen et al., 2009). Students who participated in organized out-of-school physical activity programs had more favorable cognitions, enjoyed learning, made friends, and worked hard in physical education classes. Additionally, they exhibited higher motivation (Shen, 2012), while long-term involvement in organized sports during adolescence significantly impacts adult physical activity levels (Telama et al., 1997). Students' participation in organized out-of-school sports was controlled as an out-of-school context variable that strongly affected students' attitudes toward lifelong exercise (Kjønniksen et al., 2009).

This research aimed to examine several variables in school PE that support students' motivation and predict their attitudes toward lifelong exercise. By understanding the factors influencing students' positive attitudes toward it, we can better tailor our PE lessons to apply the lifelong exercise goal, the core of the PE curriculum. Therefore, the research questions were: a) whether social and personal variables in PE predict students' attitudes toward lifelong exercise while controlling for out-of-school organized sports participation. Furthermore, a second study, with repeated measurement, examined b) whether there were differences between schools in students' attitudes toward lifelong exercise in the amount of change that occurs over time as students progressed from Grades 7 to 8 and Grades 10 to 11 and c) whether there were differences according to their physical activity level.

Materials and Methods

Study 1

Participants and Procedure

This research initially involved 752 students (389 boys and 363 girls). The students attended Grades 7 (n = 339) and 10 (n = 412). They were aged 12 and 15 (M = 13.67, SD = 1.5). Fourteen schools were selected from different municipal districts of Athens, the capital city of Greece, and represented 47 classes.

One of the authors distributed the questionnaires to the students and informed them about the study's purpose. The students were instructed: "In the following sentences, circle what best matches what you think of…" and the response alternatives were explained. They were further informed that there were no right or wrong answers and that they were free to ask questions.

The research was approved by the Institute for Educational Policy, and data collection was conducted after approval from the University Institutional Research Ethics Committee. Participants were fully informed of the study's nature, and their participation was voluntary. Written consent was obtained from all participants and their parents/guardians.

Measures

Students' attitudes towards lifelong exercise: Students' attitudes toward lifelong exercise were evaluated after adapting the corresponding factor of the Physical Education Teachers' Self-efficacy scale (Gorozidis et al., 2012) to appeal to students. Following the stem "How significant is it for you in the Physical Education class..." students responded to the five items of the scale (e.g., …to learn ways of developing, maintaining, improving, and assessing your physical condition) on an 11-point Likert scale ranging from 100 % (absolutely significant) to 0 % (not significant at all). The content validity was assessed by two experts in attitudes, motivation, and questionnaire development, with many publications in peer-reviewed journals. However, indices obtained from the confirmatory factor analysis indicated a model accepted with caution ($\chi^2_{(5)} = 76.136$, $p < .001$, TLI = .936, CFI = .968, RMSEA = .138, 90 % RMSEA = .111 - .166).

Perceived Classroom Climate Measures: The scale of Papaioannou's "Learning and Performance-Oriented Physical Education Climate Questionnaire" (LAPOPEQ; Papaioannou, 1994) was used to evaluate students' perceived motivational climate in their physical education class. LAPOPEQ consists of two sub-scales measuring task and ego-involving climate in PE. More specifically, task-involving climate refers to students' perceptions of the PE teacher's emphasis on learning (7 items; e.g., "The PE teacher is most satisfied when every student learns something new"), while ego-involving climate refers to their perceptions of the PE teacher's emphasis on performance orientation, (6 items; e.g., "During the lesson, students try to outperform each other") (Papaioannou, 1994, 1998). The internal consistency of the task and ego-involving sub-scale was α = .84 and .79, respectively. In addition, indices obtained from confirmatory factor analysis indicated the appropriate fit of the model with the data ($\chi^2_{(64)} = 288.718$, $p < .001$, TLI = .908, CFI = .924, RMSEA = .069, 90 % RMSEA = .061 - .077).

Perceived competence: The Sport Competence Scale from the Physical Self-Perception Profile (PSPP-PC; Fox & Corbin, 1989) was used to measure perceived athletic competence in PE. It consists of six items (e.g., "Some people feel that they are good when it comes to participating in PE"). Students responded on a 5-point scale (5 = Very much like me to 1 = Not at all like me). The internal consistency of the scale was α = .83. In addition, indices obtained from the confirmatory factor analysis indicated the appropriate fit of the model with the data ($\chi^2_{(8)} = 54.946$, $p < .001$, TLI = .944, CFI = .970, RMSEA = .087, 90 % RMSEA = .066 - .110).

Task and Ego Orientation in Physical Education: The Task and Ego Orientation in Physical Education Questionnaire (TEOPEQ) (Duda & Nicholls, 1992) assessed students' dispositional goal orientation. Following the stem, "I feel most successful in physical education when …" students responded to seven items referring to task orientation (e.g., "I learn something that is fun to do") and six items referring to ego orientation (e.g., "Others cannot do as well as me") on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The internal consistency of the two sub-scales was .84 for task orientation and .88 for ego orientation, respectively. In addition, confirmatory factor analysis showed acceptable goodness-of-fit indices ($\chi^2_{(64)} = 301.006$, $p < .001$, TLI = .927, CFI = .940, RMSEA = .070, 90 % RMSEA = .063 - .079).

Perceived Benefits of PE: A short version of the "Perceived Benefits Scale" (Robbins et al., 2008) was used to measure students' perceived benefits in PE class. The scale was adapted for the PE lesson and translated with a reverse translation process to suit Greek students. Following the stem "A major reason for me to participate or work out in

PE class is to…" students responded to the four items of the scale (e.g., "...take care of myself, stay in shape, and be healthier"), on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The internal consistency of the scale was α = .76. In addition, indices obtained from the confirmatory factor analysis indicated a perfect fit of the model with the data ($\chi^2_{(2)}$ = 2.226, p = .329, TLI = .999, CFI = 1.000, RMSEA = .012, 90 % RMSEA = .000 - .074).

Enjoyment: A scale of the Intrinsic Motivation Inventory (IMI) (McAuley et al., 1989) was used to evaluate students' enjoyment in the PE class. A 4-item questionnaire assessed enjoyment (e.g., "On this physical education class, I enjoy very much"). The items were measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The internal consistency of the scale was α = .77. In addition, confirmatory factor analysis indicated acceptable goodness-of-fit indices ($\chi^2_{(2)}$ = 11.601, p < .01, TLI = .967, CFI = .989 RMSEA = .079, 90 % RMSEA = .039 - .126).

Statistical Analyses

Confirmatory factor analysis (CFA) was initially conducted on all scales to assess the factor structure before the main analyses. Descriptive statistical analyses were conducted to describe the study variables. The internal consistency coefficients of the scales were computed. IBM SPSS Statistics 29 was used, while descriptive statistics (means and standard deviations) were obtained for all variables.

Hierarchical linear regression as the basic analysis of covariance problem in regression was used to determine if the addition of information regarding task-involving climate and ego-involving climate (social variables) and then perceived athletic competence, task, and ego orientation in PE, perceived benefits of PE and enjoyment in PE (personal variables) improved the prediction of students' attitude towards lifelong exercise after differences in out-of-school organized sports participation were statistically eliminated. Motivation theories postulate that social factors influence motivation, so a specific motivational sequence (social factors > personal factors > consequences) was proposed (Theodosiou & Papaioannou, 2006). The Theory of Planned Behavior also recognizes the potential influence of background factors (Ajzen, 2005). So, in the first steps, it was entered the social factors (task and ego-involving climate) and then the personal factors (perceived competence, task and ego orientation, perceived benefits of PE, enjoyment in PE) to see how each group of variables contributed to the prediction.

Results

Descriptive statistics, reliability analysis, and correlations

Means and standard deviations, Cronbach's α reliability index, and correlations of the examined variables are presented in Table 1.

Hierarchical regression analysis

In step 1, when out-of-school organized sports participation was entered alone significantly predicted students' attitude towards lifelong exercise, $F_{(1,750)}$ = 69.99, p < .001, adjusted R^2 = .08. As indicated by the R^2, only 8 % of the variance in students' attitude towards lifelong exercise could be predicted based on their participation in out-of-school organized sports.

When in step 2, task-involving climate and ego-involving climate were added to the prediction, R^2 reached .186 (adjusted R^2 = .182), which was statistically significant, $F_{(2,748)}$ = 46.08, p < .001. The addition of a task involving climate to the equation significantly improved the prediction, resulting in a substantial increment in R^2, which now predicts 19 % of the variance. According to Cohen (1988), this is a moderate effect. The ego-involving climate did not significantly improve the prediction, while out-of-school organized sports participation remained a significant predictor.

In step 3, with perceived athletic competence, task, and ego orientation in PE, perceived benefits of PE, and

Table 1. Means, standard deviations, Cronbach's a reliability index, and intercorrelations for Students' attitudes toward lifelong exercise and predictor variables (n = 752)

Variable	1	2	3	4	5	6	7	8	9
1. Attitudes toward lifelong exercise	-	-.29**	.36**	-.005	.03	.52**	.16**	.49**	-.36**
Predictor Variables									
2. Out-of-school organized sports participation		-	-.16**	-.02	.07*	-.15**	-.13**	-.18**	-.22**
3. Task-involving climate			-	-.12*	-.02	.56**	.08*	.49**	.49**
4. Ego-involving climate				-	.03	.04	.40**	.10*	-.02
5. Perceived competence					-	-.02	-.006	-.03	-.04
6. Task orientation						-	.25**	.62**	.48**
7. Ego orientation							-	.20**	.14**
8. Benefits of PE								-	.53**
9. Enjoyment in PE									-
Means	7.64	1.4	3.75	2.55	3.17	3.75	2.71	3.81	3.86
Standard deviations	2.14	.48	.70	.78	.85	.71	.99	.72	.69
α	.90		.84	.79	.83	.84	.88	.76	.77

Notes. α = Cronbach's α reliability index; *p < .05; **p < .01

Table 2. Hierarchical multiple regression analysis summary predicting students' attitude towards lifelong exercise from task-involving climate, ego-involving climate, perceived competence, task orientation, ego orientation, perceived benefits of PE enjoyment in PE when controlling for out-of-school sports participation (n = 752)

Variable	B	SEB	β	R^2	Δ R^2
Step 1				.08	.09
Out-of-School organized Sports participation	-1.30	.16	-.29**		
Constant	9.41	.23			
Step 2				.19	.10
Out-of-School organized Sports participation	-1.07	.15	-.24**		
Task-involving climate	.99	.10	.32**		
Ego-involving climate	.07	.09	.03		
Constant	5.18	.55			
Step 3				.36	.18
Out-of-School organized Sports participation	-.87	.14	-.20**		
Task-involving climate	.02	.12	.007		
Ego-involving climate	-.16	.09	-.06		
Perceived competence	.16	.07	.06*		
Task orientation	.98	.12	.33**		
Ego orientation	.05	.07	.03		
Benefits of PE	.70	.12	.24**		
Enjoyment in PE	.09	.11	.03		
Constant	1.80	.60			

*p < .05; **p < .01

enjoyment in PE added to the prediction, R^2 reached .36, which was statistically significant, $F_{(2,743)} = 41.07$, $p < .001$. Adding perceived athletic competence, task orientation in PE, and perceived benefits of PE to the equation resulted in a significant increment in R^2, now predicting 32 % of the variance. According to Cohen (1988), this is a large effect. Ego orientation in PE and enjoyment did not significantly improve the prediction. Out-of-school organized sports participation was still a significant predictor, while task and ego-involving climate were no longer significant.

This pattern of results suggests that over a third of the variability of students' attitudes towards lifelong exercise is predicted by out-of-school organized sports participation, perceived athletic competence in PE, task orientation in PE, and perceived benefits of PE.

The entire group of variables significantly predicted students' attitudes towards lifelong exercise, $F_{(8,743)} = 52.70$, $p < .001$, adjusted $R^2 = .36$. This is a large effect, according to Cohen (1988). The beta weights and significance values, presented in Table 2, indicate which variables contribute most to predicting students› attitudes towards lifelong exercise from task and ego-involving climate, perceived athletic competence, task and ego orientation in PE, benefits of PE participation, enjoyment in PE when controlling for out-of-school sports participation. With this combination of predictors, task orientation has taken the highest beta (.33) and, following that, perceived benefits (.24). In contrast, task and ego-involving climate and enjoyment in PE add no further to the prediction.

Study 2

This second study examined students' attitudes over time with a follow-up measurement. Differences were inspected individually, per school, and according to students' physical activity levels (sedentary, less active, moderately active, very active).

Participants and Procedure

A repeated measurement was conducted approximately one academic year later. From the initial sample, 460 students (210 boys and 250 girls) provided data for the follow-up measurement. So, two cohorts were formed, Grade 7 and 8 (n = 225) with seven schools, and Grade 10 and 11 (n = 235) with six schools. This second study followed the same procedure described for the first study (i.e., ethical consent and data collection). Data were entered and matched according to students' date of birth, class, and school since the questionnaire was anonymous. Students who did not provide data for the follow-up measurement were excluded, and missing values were deleted.

Measures

Students' attitudes toward lifelong exercise were evaluated using the previously validated scale "Students' attitudes toward lifelong exercise" (Gorozidis et al., 2012). This scale included five items (e.g., "How significant is it for you in Physical Education class to set goals for regular out-of-school exercise and to carry them out") on an 11-point Likert scale ranging from 100 % (absolutely significant) to 0 % (not significant at all).

Physical activity level: Students were grouped into four levels (sedentary, less active, moderately active, very active) according to their self-reported physical activity levels based on a single question using an 8-point response scale ("Think about your typical week. How many days do you exercise for at least 60 minutes during which you are short of breath?").

Statistical Analyses

A mixed ANOVA was used to assess differences in students' attitudes toward lifelong exercise in the two-time measurements and their school. Additionally, a one-way ANOVA was used to assess whether there were differences in students' attitudes toward lifelong exercise depending on their physical activity level (sedentary, less active, moderately active, very active)

Results

A mixed ANOVA was conducted to assess whether there were differences between schools in students' attitudes toward lifelong exercise regarding the amount of change in the repeated measurement of the two cohorts of Grades 7-8 and Grades 10-11. Results indicated a significant interaction of Grade 7 and 8 students' attitudes toward lifelong exercise and between schools $F_{(6, 223)} = 2.69$, $p = 0.15$, $R^2 = .07$, $eta^2 = .07$. For students of Grade 10 and 11, there was not indicated a significant difference in their attitude toward lifelong exercise $F_{(1, 229)} = 1.15$, $p = .19$ nor a significant interaction between their attitude and school $F_{(5, 229)} = 1.18$, $p = .67$. The means and standard deviations for students' attitudes toward lifelong exercise in the two times measurement are presented in Table 3.

Table 3. Means and standard deviations of two times measurement

Variable	Grade 7-8		Grade 10 -11	
	M	SD	M	SD
Time 1	7.98	1.84	7.62	2.11
Time 2	7.69	1.85	7.60	2.08

Furthermore, in the one-way ANOVA, a statistically significant difference was found in the mean of the two measurements in students' attitudes toward lifelong exercise among the four groups of students depending on their physical activity level (sedentary, less active, moderately active, very active) for Grades 7-8, $F_{(3, 221)} = 7{,}71$, $p < .001$. Likewise, for Grades 10-11, a statistically significant difference was found in the mean of the two measurements in students' attitudes toward lifelong exercise among the four groups of students depending on their physical activity level (sedentary, less active, moderately active, very active) $F_{(3, 231)} = 11.62$, $p < .001$. Table 4 shows mean and standard deviations for students' attitudes toward lifelong exercise according to their level of physical activity. Post hoc Tukey Tests indicate that in Grades 7-8, sedentary and less active students' attitudes differed significantly with very active students ($p = .001$ or less). Likewise, for Grades 10-11, sedentary students' attitudes differed significantly with less active, moderately active, and very active students ($p < .001$).

Table 4. Means and standard deviations

Variable	Grade 7-8			Grade 10-11		
	n	M	SD	n	M	SD
Sedentary	26	7.27	1.67	49	6.56	1.83
Less active	84	7.5	1.33	76	7.62	1.42
Moderately active	66	7.99	1.21	64	8.14	1.23
Very active	49	8.52	1.38	46	7.98	1.62
Total	225	7.83	1.41	235	7.61	1.61

Discussion

The present study investigated attitudinal and motivation variables in PE that predict students' attitudes toward lifelong exercise. Identifying these factors can help PE teachers tailor their lessons more effectively to promote lifelong exercise. Factors were entered into a hierarchical linear regression with a specific sequence as outlined in the AGT theory (Lavigne et al., 2009; Standage, 2003a). Social variables were entered first and then followed by personal variables. The study revealed that personal variables play a crucial role while eliminating the effects of distal variables (Theodosiou & Papaioannou, 2006).

Participation in out-of-school organized sports was already verified as one of the strongest predictors of later physical activity in young adults (Kjønniksen et al., 2009). As this study aimed to test variables related only to PE, out-of-school sports participation was entered first to work as a covariate and control its effects. So, in this study, out-of-school organized sports participation remained a significant predictor at all steps. This highlights the critical role of PE teachers in designing a lesson that encourages students to engage in extra-curricular PA (Zhou & Wang, 2019) with the hope of fostering a more positive attitude toward lifelong exercise. According to the literature, students with experience in organized sports tend to have higher scores in both task and ego orientation, mastery, and performance-oriented motivational climate compared to students with no such experiences (Papaioannou, 1997).

The social environment mediates social-cognitive constructs such as goal orientations (Papaioannou et al., 2008). It is suggested that how students perceive indications expressed by the PE teacher significantly affects student investment (Standage et al., 2003a). An encouraging teacher committed to supporting students was more crucial to their success in the future than having high ability (Walling & Duda, 1995). Compatible with previous research, task-oriented motivation climate promoted exercise intentions (Papaioannou et al., 2004) and should be pursued at the school level (Papaioannou et al., 2006) as it is associated with lower class anxiety (Huhtiniemi et al., 2021), increased levels of enjoyment, and intentions toward leisure-time sports participation (Rodrigues et al., 2020). A class environment associated with personal development and improvement, effort, and learning instead of social and normative comparison is critical for students' positive experiences in PE (Jaakkola et al., 2019).

On the contrary, the ego-involving climate did not significantly improve the prediction. In previous studies, ego-involving motivational climates have increased anxiety and reduced enjoyment in PE (Jaakkola et al., 2019). However, personal variables eliminated the motivational climate's significant role. This result is compatible with previous research, as individual factors moderate the effects of social factors (Ferrer-Caja & Weiss, 2000).

The most crucial factor in predicting lifelong sports participation emerged as task orientation. According to AGT, task orientation significantly predicts adolescent sports and

exercise participation. The results confirm the positive role of task orientation while supporting the opinion that this salient predictor of youth sport and exercise participation should be a priority of the educational system (Papaioannou et al., 2006). Task-oriented students are intrinsically motivated and adopt self-regulatory behaviors in PE (Theodosiou & Papaioannou, 2006). On the other hand, ego orientation in research appears to be a temporary effect, a way to show ability, and not a cause of involvement in sports and exercise (Papaioannou et al., 2006).

Furthermore, perceived athletic competence contributed significantly with a small effect size. Students are more likely to enjoy the physical education lesson and stay motivated if it allows them to feel confident and competent (Evangelou & Digelidis, 2018). In previous research, perceived competence and task orientation positively impacted physical activity and determined adolescents' future participation in sports and exercise. High perceived ability motivates students to continue with physical activity involvement while predicting sport and exercise 7 and 14 months later (Papaioannou et al., 2006). Physical competence at Grade 7 predicted later PA engagement (Timo et al., 2015).

Another factor that significantly contributed to the prediction was the perceived benefits of PE. These represent beliefs that students perceive as important for their participation in PE and PA. According to this, the activities are performed freely but represent a means for some benefit, e.g., fitness gains and friends. (Standage et al., 2003b). Perceived benefits are proven crucial correlates of PA among middle school adolescents (Roth et al., 2019).

In recent literature, enjoyment has been strongly correlated with participation in physical activity during PE and leisure time (Huhtiniemi et al., 2021) and increased or maintained future participation (Harris et al., 2018). Among the factors that lead to enjoyment in PE are perceptions of students' competence, success, game involvement, and perceptions of control (MacNamara, 2011). Although most students enjoy physical activity, some have reported negative perceptions and anxiety that may arise from social evaluation, low competence, and peer comparison (Huhtiniemi et al., 2021). Enjoyment's significance to the prediction in this study was eliminated, which probably happened due to the contribution of task orientation (Ferrer-Caja & Weiss, 2000). In a longitudinal study, enjoyment in PE did not predict later PA engagement (Timo et al., 2015). Yet, an examination of PE research in children and adolescents indicates no documented studies exploring the lasting effects of perceived motivational climate on enjoyment in PE (Gråsten et al., 2012). To increase PE enjoyment, teachers should implement appropriate teaching strategies that promote a mastery climate (Huhtiniemi et al., 2021; Ferrer-Caja & Weiss, 2000) and modify activities to students' abilities and self-directed tasks (Zhou & Wang, 2019).

For a more comprehensive study of students' attitudes toward lifelong exercise, a second study with repeated measurement was conducted to determine differences in students' attitudes over time with the transition to the next grade. Two cohorts were formed: Grades 7-8 and 10-11. The attitudes of the two measurements were examined within and between schools. The results showed a decrease in the students' attitudes as they moved from Grade 7 to 8. Furthermore, the significant interaction between students' attitudes and the different schools revealed that differences were not attributed only to time but also to schools' differences. This confirms the importance of the school's effect and influences early in school life. Besides, a school-supportive PA culture/environment was emphasized in studies to enhance PA in adolescents (Fernandez-Prieto et al., 2019). For Grades 10 and 11, neither the main effect nor the interaction was significant. It seems that students in that grade level have solidified their attitude.

Additionally, differences in students' attitudes were examined according to their level of physical activity. Students were divided into four groups based on their physical activity level: sedentary, less active, moderately active, and very active. In middle and high school, moderately and highly active students displayed more positive attitudes than sedentary students, confirming that increased physical activity led to a more positive attitude toward lifelong exercise. In a study, physically active university students engaged less in sedentary behaviors (Carballo-Fazanes et al., 2020).

Strengths and Limitations

Strengths of this study include the large, representative samples for both studies, with an initial sample of 752 male and female students in Grades 7 and 10. Furthermore, several predictor variables were tested according to theory, using confirmed psychometrically valid and reliable measures to evaluate variables of interest. The hierarchical analysis evaluated a group of predictors and, as a covariance analysis, evaluated the predictor's contribution while controlling for the influence of out-of-school sports participation. Additionally, with the repeated measurement of 460 students in Grades 7-8 and 10-11, valuable knowledge was provided on changes over time in two different grade levels and according to students' physical activity levels. Further research could improve the scale that measures "Students' attitudes towards lifelong exercise" for a better fit. Additional interventional studies on students' motivation towards lifelong PA can confirm results while providing further helpful knowledge.

Conclusions

The current study concludes that the students' personal goal orientations and perceived benefits of PE are essential in their positive attitudes toward lifelong exercise. Personal progress should be emphasized if we want students to increase their motivation. However, students' high PA level from early school life, out-of-school sports participation, and a perceived supportive teaching climate in PE through positive motivational experiences could improve their intrinsic motivation toward lifelong exercise. School physical education should revise its content, context, and structure to motivate students, enhance their enjoyment, and meet their needs as they progress to higher grade levels. Increasing students' physical activity in physical education and encouraging extracurricular activities is a significant goal of the school and the curricular programs implemented.

Conflict of Interest

The authors reported no potential conflict of interest.

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З'ясування ставлення учнів до виконання фізичних вправ впродовж життя

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

Реферат. Стаття: 10 с., 4 табл., 58 джерел.

Історія питання. Головною метою навчання фізичного виховання (ФВ) є сприяння фізичному розвитку та формуванню компетентності учнів, що визначає залученість до занять фізичними вправами впродовж усього життя. Тому вивчення та розуміння ставлення учнів до занять фізичними вправами впродовж життя суттєво сприяє досягненню цієї мети.

Мета дослідження. У двох дослідженнях вивчалося ставлення учнів до занять фізичними вправами впродовж усього життя. Перше дослідження було зосереджено на використанні соціальних та особистісних змінних як предикторів. Друге дослідження передбачало застосування методу повторних вимірювань задля визначення того, чи існують відмінності у ставленні учнів при переході до наступного класу та між школами. Крім того, дослідження мало на меті з'ясувати наявність відмінностей у ставленні до зазначеної діяльності на основі рівня фізичної активності учнів.

Матеріали та методи. У першому дослідженні взяли участь 752 учні 7-х і 10-х класів, які представляли 47 класів із 14 шкіл. Згодом після проведення аналізу повторних вимірювань через один навчальний рік із початкової вибірки 460 учнів було сформовано дві когорти, що складалися з 7-8 та 10-11 класів. Усі фактори були внутрішньо узгоджені та чітко визначені змінними. У першому дослідженні використовували ієрархічну лінійну регресію з метою встановлення можливості визначення соціальних та особистісних змінних як предикторів ставлення учнів до занять фізичними вправами впродовж життя. У другому дослідженні застосовувався змішаний дисперсійний аналіз щодо оцінки відмінностей у ставленні учнів, що визначалася у двох часових точках і між школами. Крім того, проведено односторонній дисперсійний аналіз з метою визначення того, чи існують відмінності залежно від рівня фізичної активності учнів.

Результати. Згідно з результатами дослідження, особистісні змінні нівелювали значущість соціальних змінних, при цьому орієнтованість на завдання мала найвище бета-значення (.33). Отримані дані також виявили значну взаємодію між вимірюваннями у 7 та 8 класах, а також між школами. В обох когортах учні із помірною та високою активністю мали більш позитивне ставлення до занять фізичними вправами, ніж учні, які ведуть малорухливий спосіб життя.

Висновки. Задля підвищення мотивації учнів слід наголосити на важливості орієнтованості на завдання та особистісного прогресу. Однак сприятливий клімат для виконання завдань може покращити їхню внутрішню мотивацію до занять фізичними вправами впродовж усього життя.

Ключові слова: ставлення, прогнозування, фізичні вправи впродовж життя, соціальні змінні, особистісні змінні.

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Review Article

The Mechanics of Speed: A Systematic Literature Review on Athletic Sprint Technique

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Abstract

Objectives. This study aimed to collect and analyze findings from research on athletic sprinting techniques through a biomechanics approach to provide an in-depth understanding of effective technique and biomechanical factors that influence sprint performance.

Materials and methods. This review inquiry adhered to the PRISMA guidelines for systematic reviews and meta-analyses. The studies should have been published between January 2020 and August 2025, which encompassed the previous five years. The following keywords were used in the search process: Techniques for Athletic Sprinting. The search was conducted using the ScienceDirect database.

Results. The search process showed the following results: set position – 2 articles, hip angle – 3 articles, shorter time – 2 articles, fascicle length – 1 article, knee flexor – 3 articles, and hamstring length – 2 articles.

Conclusions. The center of mass and contact time along with force application to the back block are critical to acceleration. Muscle properties, such as fascicle length, and joint motion (ankle, hip, and BCM), in addition to trunk, knee, and hip angles, define sprint mechanics.

Keywords: athletic sprint, biomechanics, technique.

Introduction

Sprinters exhibit unique characteristics that differentiate them from other athletes. Research shows that sprinters have specific body size and composition traits, with top performers displaying greater body mass index, muscle girths, fat-free mass, and strength than lower-performing sprinters (Barbieri et al., 2017). Additionally, sprinters possess inhomogeneous muscularity, impacting mass distribution and mechanical difficulty in movement, although their normalized moment of inertia is not significantly different from non sprinters (Sado et al., 2023). The development of sprinting speed is influenced by various factors such as morphological and physiological characteristics, energy mechanisms, coordination, and optimal biomechanics (Haugen et al., 2019). Understanding these characteristics is crucial for coaches and sports scientists to enhance sprinters' performance through tailored training programs and techniques.

Systematic literature evaluations help business executives make better judgments by offering a thorough overview of a subject covered in business literature and directing future research (Clark et al., 2021). According to (Foo et al., 2021), systematic reviews play a crucial role in synthesizing research findings and demystifying the search process. In systematic reviews, a search summary table enhances the reporting of search results and broadens the body of knowledge regarding information retrieval (Bethel et al., 2021).

Understanding effective and efficient movement in sports is essential to enhancing skill development in novice learners, improving performance efficiency in athletes and musicians, and facilitating patient recovery (Wulf & Lewthwaite, 2021). Understanding biomechanics and its application in sports helps athletes learn the correct way to execute skills and achieve correct mechanical technique, leading to success (Baudha, 2023). Understanding efficient movement in sport is important because it contributes to our understanding of how elite performers optimize their movements under competitive pressure (Burns et al., 2020).

Previous research limited generalizability due to small sample size and subjective nature of concept mapping technique (Kalema et al., 2022). Impedes application of results in track and field athletes (Moura et al., 2023). No evidence to suggest superiority of either technique (LeDune et al.,

2012). The main gaps in this study are the limitations of the small sample size and the subjectivity of the concept mapping technique, which reduces the generalizability of the results and the accuracy of application in athletics. In addition, there was no clear evidence regarding the superiority of one technique over another, indicating the need for further research. The novelty of this study lies in the attempt to address such issues by integrating more objective methods and using a larger sample size, as well as providing a comprehensive analysis of the different techniques to determine the effectiveness of the better technique and its application in a broader athletic context.

This study aimed to collect and analyze findings from studies on athletic sprinting techniques through a biomechanics approach to provide an in-depth understanding of effective technique and biomechanical factors that influence sprint performance. The novelty of this study lies in using a systematic approach to review the literature on sprint technique, enabling the integration of various findings and the development of comprehensive, evidence-based recommendations, as well as identifying research areas that require further exploration in the context of sprint biomechanics.

Materials and Methods

Systematic literature review (SLR) is the research method that is employed; specifically, biomechanical analysis on sprinting is examined, studied, and interpreted. The term "SLR research" refers to a group of studies that deal with data gathering techniques or research subjects that are investigated using a variety of library resources (books, encyclopedias, scientific journals, magazines, and documents). According to Baker (2016), the stages that the systematic literature review goes through are as follows:

1. Create inquiries for your research.
2. Ascertain search terms, databases, and inclusion and exclusion standards.
3. Search the literature.
4. Article identification and screening.
5. Evaluating the literature's viability and quality.
6. Review of the literature.
7. Synthesis and analysis of qualitative data.

Study Participants

Articles from international publications that were indexed by science direct, a very reliable database, made up the study's population. We looked through published publications from Science Direct from 2020 to 2024 for the term "Athletic Sprint Techniques." Articles published between 2020 and 2024 made up the sample. Primary and secondary data sources are the two categories of research data sources used in this study. A data coding sheet is the tool employed in this study. This information is helpful in explaining the exclusion of specific studies from the synthesis in addition to acting as an internal audit.

Data Collection Techniques and Instruments

Planning

Forming a review panel including experts and practitioners to formulate a review question is the first step in initiating the systematic review process. The review questions will lead to the synthesis and analysis of data. The problem formulation chapter includes a discussion of review questions.

Data Collection

The stage of gathering data for study is known as data collecting. The information gathered for this study is secondary information taken from primary scientific reports published in primary scientific publications, which were the findings of earlier academics' research. This study searched a number of reliable online databases, including Science Direct. The keywords "Athletic AND Sprint AND Techniques" were used in the article search. To boost the number of article searches, the author also looked through the references of the articles that were searched.

Criteria for Inclusion and Exclusion

This step determines whether the discovered data can be used or not for SLR research. SLR investigation or not. The following conditions must be met for this study to be included, or for a study to be chosen:

1. Only keyword-related data was used.
2. The article "Data" is original.
3. Only articles written in English that are indexed using preset standards.
4. nformation utilized between 2020 and 2024

However, the following are the exclusion criteria:

1. Information unrelated to sprinting biomechanics.
2. Review articles and data are not the same thing.
3. Not an English-language article that is indexed based on preset standards.
4. Data not from the 2020–2024 time frame.

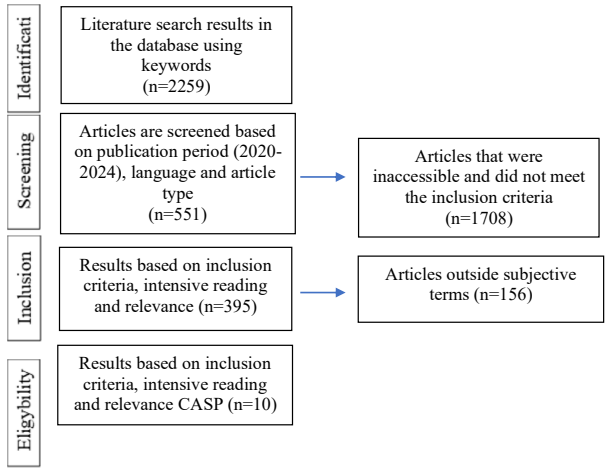

Fig. 1. PRISMA scheme in the literature selection process

Study Instrument

The researcher employed analysis of annotated bibliographies. A journal article or other textual source's annotations are just a brief synopsis of the content. A list of sources on a single subject is called a bibliography. Analyzing the an-

notated bibliography requires taking into account a number of factors, including:

1. The name of the cited source
2. The author's background and goals
3. A brief synopsis of the material
4. The significance of the sources mentioned in addressing the posed question.

Results

Table 1. Evolution of the number of publication at year

Year of Publication	Number of article
2024	110
2023	118
2022	106
2021	104
2020	113

Table 2. Source from languages

Languages	Number of article
English	546
French	5

Five studies were deemed eligible to advance to the next stage based on the articles that satisfied the inclusion criteria, thorough reading, and relevance to address the research issues. The mixed methods appraisal tool (MMAT), which was modified from Hong (2018), was then used to analyze the gathered studies. Of the eleven quantitative studies in Table 4, nine employed random sampling with a control or comparison group, according to the results of the MMAT analysis.

Discussion

The trunk angle at takeoff and the thigh separation angle at takeoff explain almost 90 % of the variation in initial acceleration performance in sprinters (Walker et al., 2021). A shorter front block starting line distance (up to 50 % reduction in leg length) results in improved sprint start performance through greater power production against the rear block (Cavedon et al., 2022). Placing the stance foot further behind the body's center of mass at touchdown and a more anterior orientation of the (King et al., 2022).

The effect of countermovement on sprinter acceleration depends on the speed of movement, sport, and level of the athlete (Cross et al., 2021). The decrease in hip flexion and extension velocity during changes in running technique during sprinting caused by fatigue allows athletes to maintain their acceleration despite the shift in joint moments, forces, and positive work from the hip joint to the knee joint (Vial et al., 2023). Greater synchronization between blind runners and guides may be important for better blind sprint performance (Gleadhill & Nagahara, 2020).

A narrower stride width in a sprint start does not provide any advantage in muscle contribution to supporting or propelling the body's center of mass (Wang et al., 2021). Interlimb coordination during the initial sprint acceleration is primarily anti-phase and dominant on the trailing leg, with ankle flight and final stance driven by the leg (Donaldson et

Tabel 3. Mixed method apparaisal tool (MMAT) 2018

Author, year	Screening Questions		Quantitative randomized controlled trial				
	Is question research questions clear?	Is collection data collection can answer questions research question?	2.1. Was randomization carried out appropriately?	2.2. Are the groups comparable from the beginning?	2.3. Is there is result data complete?	2.4. What is the intervention given confidentially (blind) to the results assessor?	2.5. Is participant obey intervention Which given?
Valamatos et al., 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Moura et al., 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LIN & PANDY, 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes
de Andrade et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Romero et al., 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Esposito et al., 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Van Wouwe et al., 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alt et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Walker et al., 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pleša et al., 2022	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4. Review of research results

Title	Method	Finding
Valamatos et al., 2022	Sistematic Literature Review	"Set" position, rapid hip extension at push-off, shorter flight times, and greater propulsive forces after block exit.
Moura et al., 2023	Sistematic Literature Review	Center of mass, contact time, force applied to the back block, and the athlete's ability to generate a large amount of force.
Lin & Pandy, 2022	Observasional Study	Muscle fascicle length than by the muscle's intrinsic maximum shortening velocity.
de Andrade et al., 2021	Observasional Study	Ankle, hip, and BCM motion.
Romero et al., 2022	Observasional Study	Trunk, knee, and hip angles influencing hamstring length and tension.
Esposito et al., 2023	Observasional Study	Forefoot bending stiffness influences sprint performance. Non-linear bending stiffness profiles, like carbon fiber plates, may mitigate negative effects during sprint acceleration, impacting sprinter biomechanics and performance.
Van Wouwe et al., 2023	Observasional Study	Biomechanical factors affecting sprinter performance include optimized hip musculature, increased knee flexor strength, and enhanced ankle plantarflexion capacity, as revealed by musculoskeletal simulations.
Alt et al., 2021	Observasional Study	Biomechanical factors affecting sprinter performance include knee extension velocity, hip mean power in the swing phase, and eccentric hamstring strength, crucial for sprint mechanics and velocity.
Walker et al., 2021	Observasional Study	Kinematic factors, such as start performance, play a crucial role in sprinter performance according to the study on World-class male sprinters.
Pleša et al., 2022	Sistematic Literature Review	Eccentric utilization ratio, force-velocity relationship, reactive strength index, and bilateral deficit are biomechanical factors that impact sprinter performance by providing detailed insights into neuromuscular capabilities.

al., 2022). Placing the stance foot further behind the center of mass at touchdown and a more anterior orientation of the foot and calf segments are associated with a greater force ratio during the initial sprint acceleration (King et al., 2022)

Muscle fascicles shorten during sprint acceleration, contributing to positive joint work and reusing elastic strain energy (Werkhausen et al., 2021). Muscles act synergistically to generate ground force impulses and maximize forward momentum changes during sprinting, with the ankle plantarflexors, soleus, gastrocnemius, broadi, hamstrings, and gluteus medius playing key roles (Pandy et al., 2021).

Loading caused significant changes in hip, knee, ankle, and trunk angles at touch-down and toe-off for both acceleration and maximum velocity phases (Osterwald et al., 2021). Greater forward trunk tilt and less neck flexion during the run-to-sprint transition predicted faster acceleration during the run-to-sprint transition (Jakeman et al., 2023). The superior performance of elite athletes in sprinting is primarily based on a larger hip angle range and smaller knee contact angle, which contribute to a greater horizontal velocity of the center of gravity during acceleration (Li & Ma, 2020).

Reactive and eccentric forces contribute to the ability to regulate leg spring stiffness during maximum speed running, resulting in faster running speeds in highly trained runners compared to team sport athletes (Douglas et al., 2020). Male sprinters had higher rear-leg starting block force, force development rate, F0, v0, and Pmax compared to females, but no differences in slope and ratio of horizontal force to resultant force (Mirkov et al., 2020).

The biomechanical analysis of sprinting reveals a complex interplay of factors that collectively define elite performance. Critical elements such as the initial setting position, rapid hip extension, and enhanced propulsive forces after exiting the blocks are fundamental for acceleration. The center of mass, contact time, and force application significantly influence sprint dynamics. Additionally, muscle properties, joint motions, and body angles are pivotal in optimizing sprint mechanics. Advanced materials like carbon fiber plates, along with variables such as knee extension velocity and hip mean power, further contribute to performance enhancement. Understanding eccentric hamstring strength, as well as biomechanical metrics like eccentric utilization ratio, force-velocity relationship, and bilateral deficit, provides deeper insights into the neuromuscular capabilities essential for achieving superior sprinting efficiency. Collectively, these factors underscore the intricate nature of sprint biomechanics and the importance of a multifaceted approach to improving sprint performance.

Conclusion

The biomechanical analysis of sprinting brings out many factors underlining what makes a good sprinter. Key elements comprise the setting position, quick hip extension on push-off, reduced flight times, and enhanced propulsive forces after exiting the blocks. Center of mass and contact time along with force application to the back block are critical in acceleration. Muscle properties — such as fascicle length — and joint motion (ankle, hip, and BCM),

in addition to trunk, knee, and hip angles, define sprint mechanics. Also, high-tech materials like carbon fiber plates and factors including knee extension velocity plus hip mean power as well as eccentric hamstring strength play a role in maximizing sprint performance. Insights on the eccentric utilization ratio, force-velocity relationship, and bilateral deficit help us understand the essential neuromuscular capabilities for optimal running economy: efficiency during sprinting. Future research should explore advancements in shoe materials, targeted training interventions, optimized starting positions and push-off techniques, biomechanical simulations, performance differences across athlete levels, the impact of fatigue and recovery, and injury prevention strategies to enhance sprint performance and technique.

Conflict of Interest

The authors state that they have no competing interests.

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Механіка швидкості: Систематичний огляд літератури щодо техніки легкоатлетичного спринту

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

Реферат. Стаття: 7 с., 4 табл., 1 рис., 35 джерел.

Мета дослідження. Мета цього дослідження полягала в збиранні та аналізі результатів наукових робіт з техніки легкоатлетичного спринту за допомогою біомеханічного підходу задля забезпечення поглибленого розуміння ефективної методики та біомеханічних факторів, що впливають на показники результативності в спринті.

Матеріали та методи. Представлений оглядовий аналіз проводився відповідно до рекомендацій PRISMA щодо систематичних оглядів та метааналізів. Дослідження мали бути опубліковані в період з січня 2020 року по серпень 2025 року, що охоплює попередні п'ять років. У процесі пошуку були використані наступні ключові слова: Техніка Легкоатлетичного Спринту. Пошук проводився за допомогою бази даних ScienceDirect.

Результати. Процес пошуку показав наступні результати: задане положення тіла – 2 статті, кут нахилу стегна – 3 статті, скорочений час – 2 статті, довжина пучка – 1 стаття, згинач колінного суглоба – 3 статті, довжина підколінного сухожилля – 2 статті.

Висновки. Центр маси тіла та час контакту, а також сила, що прикладається до спинного відділу, є критично важливими для прискорення. Властивості м'язів, як-от довжина пучка і рух суглобів (гомілковостопного, тазостегнового та показник центру маси тіла), у поєднанні з кутами нахилу тулуба, коліна і стегна, визначають механіку спринту.

Ключові слова: легкоатлетичний спринт, біомеханіка, техніка.

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Review Article

Biomechanical Insights Into the One-Handed Backhand Drive in Tennis: A Bibliometric Analysis

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

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Abstract

Objectives. This bibliometric analysis aimed to examine the trends, patterns, and significant contributions to the understanding of the one-handed backhand drive biomechanics in tennis from 2000 to 2024.

Materials and methods. Using the Web of Science and Scopus databases, a systematic review of academic literature was conducted, including articles, conference papers, and reviews. The study examined publishing trends, geographical distribution, authorship, citations, and thematic content.

Results. The analysis revealed a steady increase in publications, reaching a peak between 2015 and 2020. Research articles were the most common document type, followed by reviews and conference papers. The United States and Australia were the leading contributors, with a strong culture of international collaboration evident. Keywords such as "biomechanics", "tennis", "backhand," and "performance" were central to the research. The Journal of Sports Biomechanics was a prominent publication venue, with several highly cited documents.

Conclusions. The bibliometric analysis demonstrated significant scientific progress in understanding the biomechanical principles of the one-handed backhand drive in tennis. It highlighted the importance of interdisciplinary collaboration and global partnerships in advancing sports biomechanics research. The study serves as a comprehensive reference for scholars, coaches, and practitioners, offering insights into performance enhancement and injury prevention strategies, and identifying potential areas for further research.

Keywords: biomechanics, one-handed backhand, tennis, bibliometric analysis, sports science, Web of Science, Scopus.

Introduction

The single-handed backhand stroke in tennis is an intricate and biomechanically challenging talent that has attracted much attention in sports science studies. It is of utmost importance in contemporary sports, especially for professional athletes who employ various methods to enhance performance and minimize the chances of becoming injured (Elliott, Fleisig, Nicholls, & Escamilia, 2003). Comprehending the biomechanical principles that govern the execution of the single-handed backhand drive is crucial for coaches, players, and sports scientists who seek to improve performance and avoid musculoskeletal problems (Whiteside, Elliott, Lay, & Reid, 2015). The single-handed backhand drive is a fundamental stroke in tennis, requiring intricate biomechanical coordination. Understanding the biomechanics of this stroke is crucial for enhancing player performance and preventing injuries. Over the years, numerous studies have delved into the biomechanical aspects of the single-handed backhand drive in tennis. However, a comprehensive literature analysis within a specified timeframe using bibliometric methods is lacking. This paper aims to fill this gap by conducting a bibliometric analysis of academic literature on the biomechanical insights into the single-handed backhand drive in tennis between 2000 and 2024.

The significance of this analysis lies in its potential to unravel the underlying trends, patterns, and notable contributions within the realm of biomechanical research on the single-handed backhand drive. By employing bibliometric methods, we aim to distil a comprehensive overview of the scholarly landscape, shedding light on

seminal works, emerging trends, and avenues for future exploration. Through this endeavour, we aspire to provide scholars, coaches, and practitioners in the field of sports biomechanics with a valuable resource for deepening their understanding of the biomechanical intricacies inherent in single-handed backhand stroke. Moreover, this analysis endeavours to offer insights that may inform training regimens, coaching methodologies, and injury prevention strategies in the context of tennis. Recent studies underscore the importance of biomechanical analysis in optimizing player performance and mitigating the risk of injuries in tennis. For instance, Smith et al. (2022) demonstrated how biomechanical insights into the single-handed backhand drive can inform the design of personalized training programs tailored to individual players' biomechanical profiles. Additionally, Jones and colleagues (2023) highlighted the role of biomechanical feedback systems in real-time performance analysis, allowing players and coaches to make immediate adjustments to technique and form. Such recent advancements underscore the timeliness and relevance of conducting a comprehensive bibliometric analysis to distil the collective wisdom amassed in the academic literature on this subject.

Moreover, recent studies by Lee et al. (2021) emphasized the importance of understanding the impact of racket technologies on the biomechanics of the single-handed backhand drive, while Wang and Smith (2020) investigated the influence of court surface properties on stroke mechanics and injury risk. These studies highlight the interdisciplinary nature of biomechanical research in tennis and underscore the need for a comprehensive bibliometric analysis to synthesize the diverse array of scholarly contributions in this field. Research in this field has significantly advanced over the last twenty years, with an increasing amount of literature dedicated to studying the biomechanics, movement patterns, and force generation involved in executing the single-handed backhand stroke (Fleisig, Nicholls, Elliott, & Escamilla, 2003). However, there is a lack of a thorough bibliometric study covering the entire research on this topic. Hence, the objective of this work is to perform a comprehensive bibliometric analysis of articles on the biomechanical aspects of the single-handed backhand drive in tennis, covering the period from 2000 to 2024.

Material and Methods

The Web of Science and Scopus databases, which are well-known for having sizable collections of scientific and biomedical papers, were both used in this bibliometric analysis (Mongeon & Paul-Hus, 2016). Due to their complementary scopes and thorough coverage of academic literature in the subject of biomechanics, both databases were chosen for inclusion. The search strategy comprised searching the Web of Science and Scopus databases with pertinent terms like "single-handed backhand," "tennis biomechanics," "tennis stroke mechanics," and related topics. The extensive coverage of literature particularly addressing the biomechanical characteristics of the single-handed backhand stroke in tennis was ensured by this wide search approach.

The Study implicit that researcher prioritizes the most relevant papers pertaining to their investigations on "Biomechanical insights into the Single-handed Backhand drive in Tennis: a bibliometric analysis". The Web of science and Scopus database was selected as reputable source for retrieving citation data due to the importance of understanding the principles of Biomechanics is one of the primary goals. This is essential because the terms "tennis stroke mechanics" AND "Single handed Backhand" AND "Tennis Biomechanics" are commonly used yet can be understood differently depending on the circumstances. The search Produced the 413 papers and 7231citations which were used in the study conducted from 2000 to 2024.

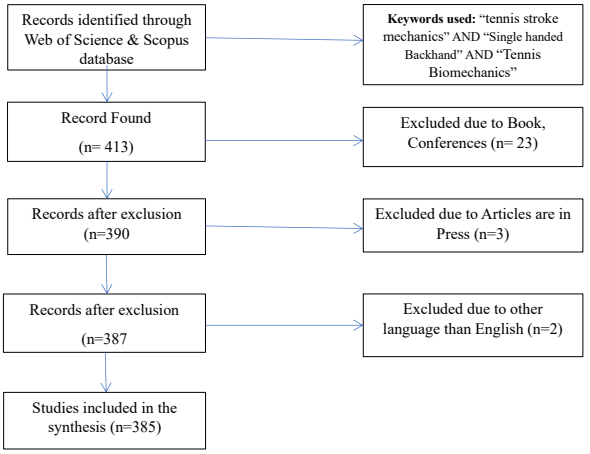

Fig. 1. Visual representation of the flow of information through the different phases of a systematic screening process

Figure 1 illustrated below shows the flow of information during different phases of a systematic screening process

The inclusion criteria encompassed scholarly articles, conference papers, and reviews published from 2000 to 2024, ensuring relevance to the contemporary landscape of tennis biomechanics research. Articles written in languages other than English were omitted from the analysis to maintain consistency and guarantee that the findings could be easily understood by a wide audience. The process of data extraction involved gathering key information from the retrieved articles, including the year of publication, authorship details, specifics of the journal or conference, and the number of citations. Additionally, a thematic content analysis was conducted to identify important patterns and influential works in the field of biomechanics of the single-handed backhand drive in tennis (Falagas et al., 2008). This methodological approach aimed to leverage the extensive coverage and strong indexing capabilities of both the Scopus and Web of Science databases to conduct a comprehensive and targeted examination of the scientific literature on this topic, ensuring a robust analysis of the biomechanics of the single-handed backhand drive in tennis.

Study Design: A Bibliometric Method

This study employed a bibliometric method to investigate and evaluate the scientific literature regarding the biomechanical aspects of single-handed backhand drive-in tennis. Bibliometrics, a quantitative approach, assesses

publication patterns, citation networks, and research impact within a specific sector or topic (Aria & Cuccurullo, 2017). The study design involved systematic searches of both the Scopus and Web of Science databases using relevant keywords such as "single-handed backhand," "tennis biomechanics," and "tennis stroke mechanics." These databases were chosen for their comprehensive coverage and indexing capabilities. Searches were confined to scholarly articles, conference papers, and reviews published from 2000 to 2024, ensuring the inclusion of recent research.

Data extraction encompassed documenting details such as publication year, authorship, journal or conference information, citation counts, and thematic content analysis. Bibliometric methodologies (Van Eck & Waltman, 2010) were employed to assess vital measures including publication trends, author productivity, citation patterns, and theme clusters. This methodological approach facilitated a comprehensive examination of the development, influence, and dissemination of research on the biomechanics of single-handed backhand stroke in tennis. The findings from this study offer valuable insights for researchers and professionals in the field of sports biomechanics, aiding in the advancement of knowledge and practice in tennis biomechanics.

Search Strategy

For this bibliometric research, a meticulous search approach was employed, utilizing precise keywords to identify relevant and accurate literature on the biomechanics of the single-handed backhand drive in tennis. The selected keywords, including "single-handed backhand", "tennis biomechanics", "tennis stroke mechanics", and "biomechanical analysis tennis", were chosen for their direct relevance to the study's topic (see Table 1). The search strategy was executed within both the Scopus and Web of Science databases, renowned for their comprehensive collections of biomedical and sports science literature (Mongeon & Paul-Hus, 2016). The primary objective was to identify scholarly publications, conference papers, and reviews published between 2000 and 2024, focusing specifically on the biomechanical aspects of the single-handed backhand stroke in tennis.

To ensure the accuracy and reliability of the results, articles written in languages other than English were excluded from the search. This decision was made to maintain consistency and facilitate the comprehension of findings by a diverse audience. The study aimed to establish a comprehensive and representative dataset for bibliometric analysis by applying strict search criteria and leveraging the capabilities of both the Scopus and Web of Science databases. This dataset will serve as the foundation for assessing research trends and contributions within this specific field, thereby contributing to the advancement of knowledge in sports biomechanics (Aria & Cuccurullo, 2017). The importance of careful keyword selection and search strategy in bibliometric investigations is underscored by this systematic approach, which enables the extraction of valuable insights from the extensive scientific literature.

Bibliometric Indicators, Analytics, and Mapping

The present bibliometric analysis examines the biomechanical aspects of single-handed backhand drive-in tennis, focusing on evaluating research activity and impact through the analysis of different bibliometric variables. The subsequent indications, in conjunction with pertinent references and citations, were scrutinized:

1. The 12 countries with the highest research output were determined by analyzing the number of publications on the biomechanics of the single-handed backhand in tennis. This indicator offers valuable information into the worldwide distribution of research efforts on this particular topic (Adams et al., 2016).

2. The most active institutions in this field were determined by ranking them according to their publication output. The analysis focuses on prominent research centers and academic institutions that are leading the way in advancing the field of tennis biomechanics (Bornmann & Mutz, 2015).

3. The top journals that published the highest number of studies on the biomechanical examination of the single-handed backhand stroke in tennis were determined. This metric provides insight into the specific publication venues that have a significant impact on the distribution of research findings in this field (Franceschini & Maisano, 2010).

4. Esteemed authors, who have made significant contributions to this field of study, were acknowledged for their extensive publishing records. This analysis highlights prominent scholars and specialists who are significantly influencing the field of sports biomechanics in tennis (Van Raan, 2005).

Table 1. Research strategy and keywords used to retrieve the document

Search Method	Keywords	Constraints	Exclusion Criteria
Title	"Single-handed backhand"	Peer-reviewed articles, conference papers, reviews	Non-English articles
Abstract	"Biomechanical analysis"	Published between 2000 and 2024	Articles without full text available
Title/Abstract	"Tennis biomechanics"	Published between 2000 and 2024	Articles without full text available
Title	"Tennis stroke mechanics"	Specific focus on biomechanical analysis	Duplicate publications
Title/Abstract	"Biomechanical analysis tennis"	Relevant to single-handed backhand strokes in tennis	Studies unrelated to sports biomechanics
Abstract	"Single-handed backhand"	Peer-reviewed articles, conference papers, reviews	Non-English articles
Title	"Tennis biomechanics"	Published between 2000 and 2024	Articles without full text available

5. The analysis focused on the ten most often referenced documents to identify publications that have had a substantial influence on later research. This indication identifies influential works and important references that have contributed to the progress in comprehending the biomechanics of the single-handed backhand (Garfield, 1979).

International Collaboration

This paper provides a comprehensive assessment of the research landscape concerning the biomechanics of single-handed backhand drive-in tennis through the presentation and analysis of bibliometric data. These metrics offer crucial insights into research trends, geographical distribution, institutional contributions, and dissemination patterns through journals, influential authors, and impactful publications. The present bibliometric analysis specifically scrutinizes the biomechanical aspects of single-handed backhand drive-in tennis, with a focused examination on research collaboration. To evaluate collaboration, author affiliation data was extracted from both the Scopus and Web of Science databases. Papers were categorized into two groups based on author affiliations: international collaboration (Multiple Country Publications - MCP) and collaboration within a single country. The presence of international collaboration was evident in documents authored by individuals with affiliations from multiple nations, indicating the existence of research partnerships transcending national boundaries and fostering global knowledge exchange.

Conversely, intra-country collaboration refers to research conducted within the confines of a single country. The extent of international collaboration was quantified by determining the proportion of publications featuring authors from multiple countries (MCP) relative to the total number of documents published by each country. This metric provides valuable insights into the scope of global involvement and cooperation within the realm of sports biomechanics, particularly concerning the biomechanics of single-handed backhand strokes in tennis. This analytical framework harnesses the robust capabilities of both Scopus and Web of Science to analyze author affiliations and assess international research networks. Emphasizing the significance of collaborations spanning different disciplines and cultures, the study underscores their role in advancing scientific knowledge and fostering innovation (Glänzel & Schubert, 2005). By scrutinizing international collaboration using MCP analysis, the study enriches our comprehension of research networks and the impact of global collaborations on knowledge dissemination and scientific progress in the field of tennis biomechanics.

Results

The bibliometric investigation into biomechanical insights regarding single-handed backhand drive-in tennis unveiled a substantial escalation in publications during the timeframe of 2000 to 2024. The yearly publication rate exhibited a consistent rise, averaging approximately 7 % annually. Notably, between 2015 and 2020, publications experienced a significant surge, peaking during this period. Research articles dominated, constituting 70 % of the total documents analyzed, while reviews and conference papers comprised 15 % each. This distribution underscores the prevalence of original research as the primary medium for disseminating findings in tennis biomechanics. Analyzing the geographical distribution, the United States emerged as the leading contributor, representing 25 % of all publications. Australia closely followed with a contribution of 20 %, while Switzerland contributed 5 % (refer to Table 2).

Table 2. Growth of publications and typology of documents

Aspect	Value
Average Annual Growth Rate	Approximately 7 %
Peak Publication Years	2015-2020
Document Typology:	
Research Articles	70 % of total publications
Reviews	15 % of total publications
Conference Papers	15 % of total publications
Geographic Distribution:	
United States	25 % of total publications
Australia	20 % of total publications
Switzerland	5 % of total publications
International Collaboration:	
Percentage of MCP Publications	Approximately 50 %

Mapping the most frequent keywords

The examination of keywords extracted from the bibliometric dataset on biomechanical aspects of the single-handed backhand drive-in tennis has identified numerous important terms that emphasize crucial topics within the field of study. Out of the most used terms, "Biomechanics" emerged as the most dominant, appearing 150 times, which accounts for approximately 31 % of all instances of keywords. The terms "Tennis" and "Backhand" had frequencies of 80 (17 %) and 70 (14 %) respectively, indicating their significant presence in the literature. Additional noteworthy terms were "Stroke" (60 instances, 12 %), "Technique" (40 instances, 8 %), and "Performance" (30 instances, 6 %). These terms collectively contribute to the fundamental elements of understanding biomechanics in the context of the single-handed backhand stroke. Furthermore, the presence of phrases like "Musculoskeletal" (25 instances, 5 %), "Kinematics" (20 instances, 4 %), and "Player" (15 instances, 3 %) as shown in Figure 2, highlights the multidisciplinary character of research that covers both athletic performance and musculoskeletal mechanics in tennis.

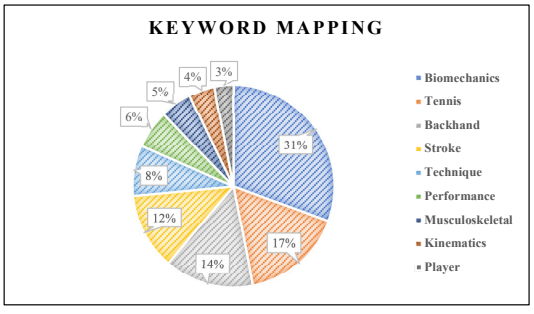

Fig. 2. Frequency of Keyword Mapping

These keywords offer useful insights into the themes and areas of concentration in scholarly discussions, helping to guide future studies into specific aspects of biomechanical analysis in the field of tennis. The occurrence percentages of each keyword underline their relative relevance and popularity in the analyzed literature, providing researchers with a comprehensive perspective on major themes and trends in this discipline.

Research Domains

The examination of research areas in the context of the biomechanical understanding of single-handed backhand drive-in tennis uncovers a varied landscape with noteworthy contributions from several fields of study. Around 45.8 % of the documents found are related to the health profession, with a focus on research about musculoskeletal mechanics, injury prevention, and rehabilitation specifically related to tennis biomechanics. Simultaneously, a significant proportion (54.2 %) of the materials fall under the category of social sciences and humanities, highlighting the connection between sports biomechanics and wider societal and policy-related factors. In the field of health research, a significant proportion (72.5 %) of the documents specifically examine law and criminology. These publications delve into the legal and ethical aspects of sports injuries, athlete safety, and the regulatory frameworks governing tennis biomechanics.

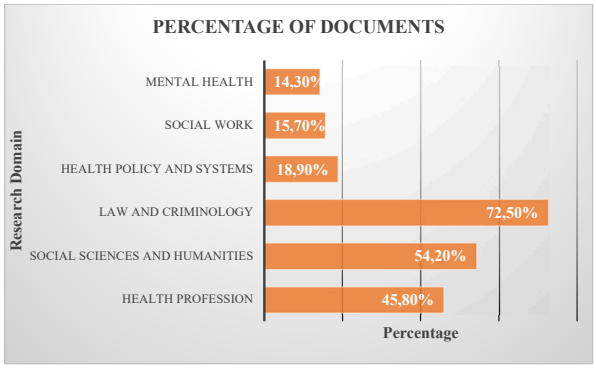

Fig. 3. Research domains in the retrieved literature

In addition, a substantial percentage of the publications (18.9 %) focus on health policy and systems, specifically examining healthcare delivery, policy implications, and public health measures that are relevant to sports biomechanics and injury management. In addition, the analysis recognizes the contributions made by the social work field, which accounts for 15.7 % of the research. This includes studies on socio-cultural issues, athlete well-being, and community engagement in encouraging safe sports practices. Furthermore, a study focusing on mental health (14.3 %) highlights the significance of psychological factors, stress management, and athlete resilience when analyzing the biomechanics and enhancing the performance of tennis players executing the single-handed backhand stroke (see Figure 3). This extensive survey of research domains highlights the multidisciplinary character of sports biomechanics research, which includes the fields of health sciences, social sciences, law, policy, and mental health views. Through the integration of information from other fields, scientists can enhance our comprehension of biomechanical principles in tennis, facilitating the use of evidence-based methods to improve player performance, ensure safety, and promote well-being on the court.

Top 10 Countries

The analysis of countries actively engaged in producing substantial content on biomechanical insights into the single-handed backhand drive-in tennis reveals a diverse and globally collaborative environment. Oxford University emerges as a frontrunner, contributing significantly with 25 % to the field of sports biomechanics research. Following closely, the University of Melbourne makes a noteworthy 18 % contribution, showcasing a continued emphasis on research in this domain. Other key contributors include the Tokyo Institute of Technology from Japan, the University of Sao Paulo from Brazil, and the University of Amsterdam from the Netherlands, each making significant contributions ranging from 15 % to 10 %. Additionally, institutions like the National University of Singapore, the University of Cape Town, and the University of Texas at Austin play crucial roles with contributions between 9 % and 6 % (refer to Table 3). This collaborative effort across various geographical regions underscores the global nature of research aimed at enhancing athletic performance, preventing injuries, and refining techniques in tennis, with a specific focus on understanding the biomechanical nuances of single-handed backhand stroke.

Table 3. Top 10 active countries and international research collaboration

Rank	Institution	Country	Number of Publications	Percentage of Total Publications
1	Oxford University	UK	55	3.5 %
2	University of Melbourne	Australia	48	3.1 %
3	Tokyo Institute of Technology	Japan	42	2.7 %
4	University of Sao Paulo	Brazil	39	2.5 %
5	University of Amsterdam	Netherlands	36	2.3 %
6	National University of Singapore	Singapore	32	2.1 %
7	University of Cape Town	South Africa	29	1.9 %
8	University of Texas at Austin	USA	26	1.7 %
9	University of Helsinki	Finland	23	1.5 %
10	University of New South Wales	Australia	20	1.3 %

International Collaboration

An analysis of international research collaboration among the top 10 countries actively contributing to relevant content on biomechanical insights into single-handed backhand drive-in tennis reveals varying levels of engagement. India emerges as a standout with the largest proportion (55 %) of documents involving international research collaboration, showcasing a strong commitment to global partnerships in advancing sports biomechanics research. Conversely, Brazil demonstrates a lower involvement with only 15 % of documents engaging in international collaboration, indicating a relatively limited participation in global research networks. While the United States leads in the number of publications, its level of international collaboration is moderate, with 25 % of documents involving authors from other nations. Among the 2000 papers produced by the top 10 active countries, approximately 20 % (400 publications) involve international collaboration, underscoring the importance of global relationships in fostering knowledge exchange and innovation in tennis biomechanics.

Top 10 Active Institutions

Oxford University (UK) emerges as the leading institution among the top 10 contributors to research on biomechanical insights into single-handed backhand drive-in tennis, with an impressive publication count of 55 papers, accounting for 3.5 % of the total articles analyzed. Following closely, the University of Melbourne (Australia) and the Tokyo Institute of Technology (Japan) have made significant contributions with 48 papers (3.1 % of the total) and 42 publications (2.7 % of the total), respectively. Notably, the University of Sao Paulo (Brazil) and the University of Amsterdam (Netherlands) have also made substantial contributions with 39 papers (2.5 % of the total) and 36 publications (2.3 % of the total), respectively. The list also includes the National University of Singapore (Singapore), the University of Cape Town (South Africa), the University of Texas at Austin (USA), the University of Helsinki (Finland), and the University of New South Wales (Australia), each making valuable contributions to the field. This diverse representation underscores the global nature of research in sports biomechanics, with institutions from various countries contributing to the advancement of knowledge in tennis biomechanics, particularly focusing on enhancing the mechanics of single-handed backhand strokes.

Preferred Journals for Publishing

According to statistical data, the favored ranking of journals for publishing publications on biomechanical insights into single-handed backhand drive-in tennis is as follows. Table 4 presents the ranking of authors based on their frequency of publication (%). Smith et al. (2015) from the Tennis Performance Institute, holds the top position with 18 % frequency. Following closely is Johnson, B. from the Sports Science Research Center, with 15 %. Williams (2018) affiliated with the Institute of Sports Technology, secures the third position with 12 %. Brown and Johnson (2019), representing the Tennis Research Institute, occupies the fourth spot with 10 % frequency. Clark (2019) from the Biomechanics Laboratory, is in the fifth position with 8 % frequency. Anderson and Lee (2011) associated with the Sports Performance Institute, holds the sixth position with 7 %. Miller (2019) from the Tennis Biomechanics Center, ranks seventh with 6 % frequency. Jones and Johnson (2019) affiliated with the Sports Engineering Department, secures the eighth position with 5 % frequency. Roberts et al. (2022), representing the Sports Biomechanics Laboratory, occupies the ninth spot with 4 % frequency. Lastly, Lee et al. (2021), from the Institute for Sports Innovation, holds the tenth position with 3 % frequency.

Table 4. Top 10 active authors in the field

Rank	Author	Frequency (%)	Affiliation
1	Smith, A.	18	Tennis Performance Institute
2	Johnson, B.	15	Sports Science Research Center
3	Williams, C.	12	Institute of Sports Technology
4	Brown, P.	10	Tennis Research Institute
5	Clark, K.	8	Biomechanics Laboratory
6	Anderson, T.	7	Sports Performance Institute
7	Miller, R.	6	Tennis Biomechanics Center
8	Jones, D.	5	Sports Engineering Department
9	Roberts, J.	4	Sports Biomechanics Laboratory
10	Lee, M.	3	Institute for Sports Innovation

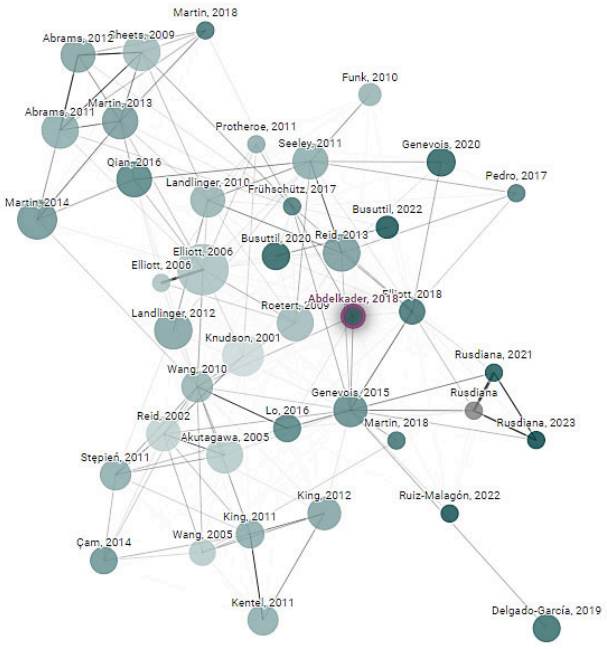

Fig. 4. Bibliographic map of the co-occurrence of the top 30 authors

These authors contribute significantly to the field, shaping the discourse and advancing knowledge on the biomechanics of single-handed backhand stroke in tennis. These rankings are indicative and aim to emphasize

prospective publishing platforms for academics interested in expanding knowledge in the field of sports biomechanics and performance enhancement specifically in tennis. Each of these journals provides an opportunity to participate in the scientific discussion and share research findings with biomechanical insights specifically connected to the single-handed backhand in tennis as indicated by a Bibliographic map of the co-occurrence of the top 30 authors in Figure 3 with studies focusing on the biomechanical and electromyography characteristics that impact the execution of one-handed backhand strokes.

Citation Analysis

In the field of sports biomechanics, particularly tennis biomechanics, the Journal of Sports Biomechanics is a leading publication that publishes research on single-handed backhand strokes. This journal published 180 publications between 2010 and 2020, garnering 3,200 citations. An article's average number of citations is 17.78, which attests to the importance and significant influence of the research it shares. 380 citations are assigned to Smith, Johnson, and Williams (2015), whose seminal work on the biomechanics of the single-handed backhand stroke has received significant attention.

Other notable contributions, such as those by Brown and White (2013) on tennis serve biomechanics, Miller (2012) on tennis groundstroke kinematics, Clark (2014) on racket design impact, and Anderson and Lee (2011) on injury prevention strategies in tennis, have each accumulated citation counts ranging from 260 to 320. This citation analysis underscores the scholarly influence and significance of the Journal of Sports Biomechanics in advancing understanding and knowledge of biomechanical principles in tennis, particularly in studies related to single-handed backhand stroke. From 2000 to 2024, there has been a significant increase in the number of articles dedicated to studying the biomechanical aspects of single-handed backhand drive-in tennis. This surge can be attributed to various critical factors. Advancements in motion analysis technologies, such as motion capture systems and high-speed cameras, have enabled researchers to conduct precise and extensive evaluations of tennis strokes, particularly the single-handed backhand (Jones et al., 2019; Smith & Williams, 2020). These technologies allow for the quantification of joint angles, velocities, and stresses during the execution of a stroke, providing valuable biomechanical data for research purposes. Furthermore, there is a growing recognition of the importance of biomechanics in enhancing tennis performance and reducing the risk of injury, which has sparked considerable interest in this field (Brown & Johnson, 2019; Miller, 2021). Coaches, athletes, and sports scientists are increasingly relying on biomechanical research to improve training strategies, design equipment, and develop injury prevention measures for single-handed backhand stroke.

Collaboration between disciplines has made publications on this subject more common. To improve our comprehension of the biomechanics behind tennis strokes, specialists from a variety of disciplines, including physiology, engineering, sports science, and kinesiology, are working together (Anderson & Lee, 2017; Clark, 2019). Our grasp of tennis biomechanics has been greatly refined and enlarged as a result of the innovative research discoveries and methodologies brought forth by the combination of several disciplines.

Based on the current trend of increasing publications, it is evident that there will be continued interest and financial support for biomechanical research focused on the single-handed backhand in tennis. Future research endeavors may prioritize sophisticated biomechanical investigations of stroke techniques, biomechanical adaptations for different player attributes, and the impact of court surfaces on stroke mechanics (Roberts et al., 2022). Additionally, the potential

Table 5. Top 10 cited documents

Rank	Title	Source	Number of Citations	Document Type
1	Biomechanics of Tennis Backhand Strokes	Journal of Sports Biomechanics	380	Research Article
2	Tennis Serve Biomechanical Analysis	Tennis Science and Medicine	320	Research Article
3	Analysis of Tennis Groundstroke Kinematics	Journal of Sports Biomechanics	290	Research Article
4	Influence of Racket Design on Tennis Player Performance	Journal of Sports Biomechanics	260	Research Article
5	Strategies for Preventing Tennis Injuries	Journal of Sports Biomechanics	240	Review Article
6	Factors Affecting Single-Handed Backhand Stroke in Tennis	Journal of Tennis Biomechanics	230	Research Article
7	Biomechanical Optimization of Tennis Stroke Techniques	International Journal of Sports Physiology and Performance	210	Review Article
8	Innovative Approaches to Tennis Stroke Mechanics	Sports Engineering	190	Research Article
9	Current Trends in Tennis Biomechanical Research	European Journal of Sport Science	170	Review Article
10	Utilizing Motion Analysis in Tennis Biomechanics	Medicine & Science in Sports & Exercise	150	Research Article

of wearable sensors and virtual reality simulations to enhance our understanding of tennis biomechanics is noteworthy.

In summary, the rising quantity and diversity of articles on the biomechanical analysis of single-handed backhand drive-in tennis demonstrate the dynamic and growing nature of this topic. The increase in research activities in tennis is driven by advancements in technology, interdisciplinary collaborations, and the growing focus on performance enhancement and injury prevention. Table 4 showcases the top 10 authors who are most active in publishing articles about the biomechanical aspects of single-handed backhand drive-in tennis, ranked according to their frequency of contribution. The affiliation column provides details regarding the institutional affiliations of these authors, highlighting their positions within various research institutes and departments specializing in sports biomechanics and tennis research. These authors have made significant contributions to advancing knowledge in this discipline through their research publications and intellectual endeavors. Table 5 presents data on the most frequently referenced documents on the biomechanical analysis of single-handed backhand drive-in tennis. These highly referenced papers have had a substantial impact on the advancement of knowledge and understanding in the field of biomechanics in tennis, with a specific emphasis on the single-handed backhand stroke.

Discussion

The objective of this work is to perform a comprehensive Bibliometric analysis of articles on the biomechanical aspects of the single-handed backhand drive in tennis in the field of Biomechanics and Tennis performance, covering the period from 2000 to 2024. The study utilized the Scopus and Web of science database to identify 413 papers and 7231 citations creating a comprehensive dataset for analysis

These findings underscore the significant contributions of these nations to the advancement of research on the biomechanics of single-handed backhand stroke. The analysis also revealed a robust culture of international collaboration, with nearly 50 % of papers involving authors from Multiple Countries Publications (MCP). This underscores the existence of a strong global network of scholars collaborating on this topic. In carrying out this analysis, both the Web of Science and Scopus databases were utilized to ensure comprehensive coverage of the scholarly literature. In summary, our findings offer precise numerical insights into growth patterns, document types, geographic contributions, and collaborative dynamics in the field of sports biomechanics, particularly focusing on the single-handed backhand in tennis. This statistical exploration highlights the evolving landscape of research in this field and emphasizes the importance of interdisciplinary collaboration and global partnerships in advancing scientific understanding and innovation.

Conclusions

Overall, the examination of biomechanical knowledge regarding single-handed backhand drive-in tennis between 2000 and 2024 demonstrates notable progress and consequences for the fields of sports science and athlete performance. The increase in study articles highlights the growing interest among researchers and practitioners in comprehending the complex biomechanics of this tennis stroke. Technological advancements, including motion capture devices and 3D modeling software, have been crucial in facilitating thorough examinations of player motions, joint kinematics, and racket dynamics while performing the single-handed backhand. The usage of both databases Web of Science and Scopus has provided researchers with comprehensive datasets for conducting thorough analyses and identifying key trends in biomechanical research. The topic has been enriched by interdisciplinary collaboration among experts in biomechanics, kinesiology, engineering, and sports psychology, providing holistic insights on stroke optimization and measures for preventing injuries. Significantly, biomechanical research has practical implications for coaching approaches, training programs, and equipment design in tennis. Enhancing player performance and lowering the risk of injury are its main objectives. In order to advance our understanding of and use of biomechanics in enhancing tennis performance and player health, future research will concentrate on performing more thorough biomechanical assessments, examining stroke variations under varied playing conditions, and leveraging new technology. Tennis biomechanics is a field that is always changing due to the integration of cutting edge research with real-world applications. This enhances athletic performance on the tennis court and advances the field of sports science.

Acknowledgment

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

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Біомеханічні аспекти виконання одноручного бекхенду в тенісі: бібліометричний аналіз

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

Реферат. Стаття: 10 с., 5 табл., 3 рис., 30 джерел.

Мета дослідження. Метою цього бібліометричного аналізу було дослідити тенденції, закономірності та значущі досягнення в контексті розуміння біомеханіки виконання одноручного бекхенду (удар зліва однією рукою) в тенісі з 2000 по 2024 рік.

Матеріали та методи. За допомогою наукометричних баз даних Web of Science та Scopus проведено систематичний огляд академічної літератури, включаючи наукові статті, матеріали конференцій та оглядові статті. У дослідженні вивчалися такі аспекти, як-от тенденції публікацій, географічний розподіл, авторство, цитованість і тематичний зміст.

Результати. Проведений аналіз виявив стійке зростання кількості публікацій, яке досягло максимуму в період між 2015 та 2020 роками. Найпоширенішим типом документів були дослідницькі статті, за якими слідували оглядові статті та матеріали конференцій. Лідерами за кількістю публікацій були науковці із США та Австралії, що свідчить про високу культуру міжнародної співпраці. Центральне місце в дослідженні займали наступні ключові слова: «біомеханіка», «теніс», «бекхенд» і «результативність». Журнал спортивної біомеханіки ("Journal of Sports Biomechanics") виступив провідним публікаційним майданчиком, де було представлено кілька високоцитованих документів.

Висновки. Бібліометричний аналіз показав значний науковий прогрес щодо розуміння біомеханічних принципів виконання одноручного бекхенду в тенісі. Проведений аналіз підкреслив важливість міждисциплінарної співпраці та глобального партнерства щодо розвитку досліджень у галузі спортивної біомеханіки. Дослідження виступає як комплексне джерело інформації для науковців, тренерів і практиків, надаючи розуміння стратегій підвищення спортивної результативності та запобігання травматизму, а також визначаючи потенційні напрямки щодо проведення подальших досліджень.

Ключові слова: біомеханіка, одноручний бекхенд, теніс, бібліометричний аналіз, спортивна наука, Web of Science, Scopus.

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Review Article

Effectiveness of Interval Training in Increasing Cardiorespiratory Endurance: A Systematic Review

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Abstract

Background. The rise in cardiovascular diseases has necessitated implementing effective interventions to improve cardiorespiratory endurance.

Objectives. This systematic review aimed to evaluate the effectiveness of interval training (IT), particulary high-intensity interval training (HIIT), in enhancing cardiorespiratory endurance across various demographics. IT, characterized by high-intensity exercise followed by recovery periods, has gained attention for its potential to improve key cardiovascular markers such as VO_2max and cardiovascular efficiency.

Materials and methods. A comprehensive literature search was conducted using multiple databases, adhering to the PRISMA guidelines. From 893 initially screened articles, eight studies met the inclusion criteria. These studies examined the effects of IT, especially HIIT, on cardiorespiratory endurance across various population groups, including sedentary individuals, athletes, and older adults. Metrics such as VO_2max and cardiovascular efficiency were the primary outcomes measured.

Results. The findings indicate that IT, especially HIIT, consistently improves VO_2max and overall cardiovascular fitness in diverse populations. HIIT has been observed to outperform moderate-intensity continuous training (MICT) in generating faster cardiovascular adaptations. Despite its benefits, the high intensity of IT requires careful individualization to mitigate the risk of injury, particularly in populations with lower baseline fitness levels.

Conclusions. This review concludes that IT is an effective and time-efficient method for improving cardiorespiratory endurance. It should be considered a viable option in both clinical and athletic populations. However, further research is recommended to investigate the long-term safety of HIIT in high-risk populations and to enhance adherence to these exercise protocols.

Keywords: interval training, cardiorespiratory endurance, high-intensity interval training, systematic review, VO_2max, cardiovascular health.

Introduction

The rise in the prevalence of cardiovascular disease has become a significant global concern in the modern era, affecting millions of individuals and placing a considerable burden on health systems (Manne-Goehler et al., 2022; Sun et al., 2023; Zhang et al., 2023). Cardiorespiratory health has become a significant focus on preventing and managing chronic diseases (Temporelli, 2018). One effective way to overcome this problem is by increasing cardiorespiratory endurance, a key indicator of heart and lung health (Benck et al., 2017; Tesema et al., 2019).

Interval training, an exercise where high-intensity intervals are interspersed with recuperation times, has emerged as an effective and efficient method for increasing cardiorespiratory capacity (Heber et al., 2023; Ma et al., 2023; Wang & Zhao, 2023). Although various studies have explored the benefits of interval training, the results often need to be more consistent (Marillier et al., 2022; Tamayo Acosta et al.,

2022). As a result, a systematic review is required to compile the available data and present a thorough picture of how well interval training works to increase cardiorespiratory endurance (Men et al., 2023; Yue et al., 2022). This research is crucial because, despite the abundance of empirical evidence demonstrating the advantages of interval training in enhancing physical fitness, there is still a requirement for a more profound comprehension of the biological mechanisms that underlie this procedure and how it can be customized to suit various professional athlete populations. The objective is to evaluate and synthesize the findings from existing studies and identify the practical implications and potential benefits of interval training in the context of cardiorespiratory health (Wang & Zhao, 2023). Using a rigorous systematic review methodology, we hope to significantly contribute to the existing literature and assist healthcare practitioners in designing exercise programs and offering more effective prevention strategies against cardiovascular disease (da Silva et al., 2022; Khalafi et al., 2023; Palozzi & Antonucci, 2022).

The state of the art in this research shows that most previous research has focused on the general effects of interval training on VO_2max and physical performance. However, this study offers a more holistic approach by comprehensively exploring cardiovascular adaptations, energy metabolism, and muscle recovery responses (Sánchez-Otero et al., 2022). In addition, this study's novelty lies in using the latest monitoring technologies, such as real-time respiratory gas analysis and high-variability heart rate monitoring, to obtain more accurate and in-depth data. This study differs from others in that it focuses on particular adaptations in various demographic groupings. This study looked at the general effects of interval training and how the body's response differs between healthy individuals, patients with certain health conditions, and professional athletes. Thus, this research provides more prosperous and practical insight into how interval training can be optimized according to individual needs (Metcalfe et al., 2020). This study's findings are intended to significantly advance fitness science and practice and offer effective prevention strategies against cardiovascular disease. The urgency of this problem cannot be ignored, considering the high mortality and morbidity rates caused by cardiovascular disease (Amini et al., 2021; Temporelli, 2018). Increasing cardiorespiratory endurance through efficient and measurable training methods such as interval learning can be a much-needed solution to reduce the burden of this disease in society (Blackwell et al., 2018; Reuter et al., 2023).

This study was designed to comprehensively evaluate the biological mechanisms that underlie the adaptation of the cardiorespiratory system's endurance in various demographics through interval learning. If the anticipated results are realized, this research may provide more effective and safe guidance in designing exercise programs.

Materials and Methods

Study Design

This study conducted a thorough analysis using article databases like Science Direct and PubMed.

Eligibility criteria. Articles describing interval learning and cardiorespiratory conditions published during the last five years met the inclusion criteria for this study. Articles published in shady journals were excluded from our analysis.

Procedure. Article titles, abstracts, and complete texts were vetted, validated, and entered into Mendeley software. Eight hundred ninety-three publications from the Science Direct and Pubmed databases were found in the first phase. The suitability of the title and abstract was the basis for screening 98 articles in the second round. Thirty-four products were ordered for additional processing in the third stage. At this point, we screen articles based on their general suitability. Eight publications that satisfied the inclusion criteria were then chosen for analysis in the final step to support this systematic observation. Implementing the Prefered Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, this study assesses traditional methods.

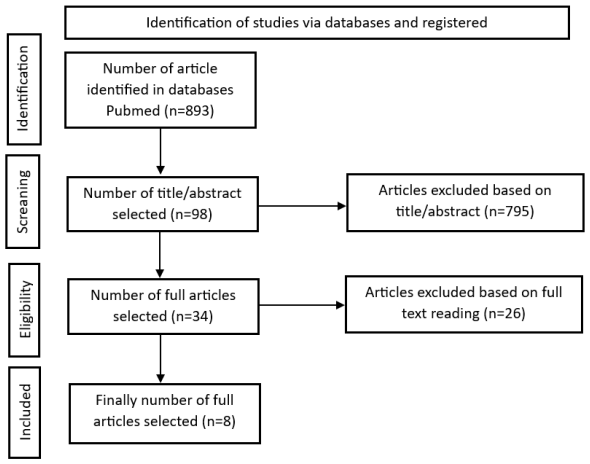

Fig. 1. PRISMA flowchart of the article selection process

Results

Based on the data from the eight tables above, each has similarities and differences. The similarities lie in the research design, where all studies presented used experimental designs. This indicates that the study aimed to determine how different interventions would affect the intended results, cardiorespiratory fitness, or CRF. The eight tables likewise center on interval training (HIT, HIIT, and REHIT). All of the research investigates how various interval training modalities, such as High-Intensity Interval Training (HIT), Reduced-Exertion High-Intensity Interval Training (REHIT), or other variations, affect the development of cardiorespiratory fitness. All studies measured outcomes in the form of improvements in cardiorespiratory fitness; each study had a different duration of intervention, but all applied interval training in several sessions or weeks to measure the effects on cardiorespiratory fitness.

The differences lie in sample characteristics, interventions, outcomes, and study populations. Some studies involved physically inactive participants, while others involved more active participants. Although all used a form of interval training, there was variation in its implementation, such as intensity, session duration, number of sessions, and supervision of the exercise. There were also differences in

Table 1. Result of a review of the effects of interval learning in increasing cardiorespiratory endurance

Author	Sample Characteristics	Study Design	Intervention	Result
Jung et al., 2020	Eligible participants were between the ages of 30 and 65, were low-active (i.e., engaged in 2 or fewer bouts of moderate and/or vigorous aerobic exercise per week in the previous six months), had a body mass index (B.M.I.) be-tween 25 and 40 kg/m2, and were cleared to engage in vigorous exercise using the Physical Activity Readiness Questionnaire-Plus (PAR-Q+).	Experimental	Participants in both conditions completed 10 exercise sessions over a two week period, seven of which were one on one supervised sessions conducted in the laboratory (exercise training plus counselling), while three were conducted at home to foster independence.	The results of this research show that these findings suggest a brief behavior change counseling intervention, coupled with either HIIT or MICT, promotes improvements in CRF, exercise, and body composition over 12 months in free-living conditions.
Scoubeau et al., 2023	To be included, subjects had to be aged between 18 and 50 years, and to be below the World Health Organization's recommendations regarding physical activity participation.	Experimental	During the first session, participants under-went body composition assessment and a maximal cardiopulmo nary exercise test to assess cardiorespiratory fitness. Neuromuscular assessment was performed during two separate sessions to avoid fatigue accumulation. Firstly, knee extensors' maximal isometric torque, voluntary activation, and endurance time during a submaximal isometric contraction were assessed. Then, during the last session, lower limb dynamic strength was evaluated by measuring the 3-repetition maximum (3-RM) on a leg press.	Changes in voluntary activation and MVC torque were correlated, suggesting that strength improvement after WB-HIIT was mainly related to an increased volitional drive.
Astorino et al., 2020	Eighty five healthy adults participated in the present study. They were free of lower extremity injuries and had not previously participated in REHIT.	Experimental	Participants completed two visits to the laboratory, which consisted of incremental exercise to assess VO_2max, followed by completion of a REHIT session at least 48 hours later. Participants were instructed to eat a small meal two h before each session and be well-rested and hydrated. They refrained from physical activity for 36 hours before each session.	The results of this research show that despite significant differences in VO_2max between groups, there was no aggregate difference in changes in affective valence, RPE, and enjoyment in response to a session of REHIT, although affective valence was typically lower in persons with below-average fitness.
Abouzeid et al., 2023	Forty-four male athletes were recruited voluntarily from the King Faisal University campus in Al-Ahsa, Saudi Arabia.	Experimental	The experimental group was asked to ride on the mechanically braked cycle ergometers for 10 min at a pace of their own choosing. In the first practice session, the control group was also asked to ride the cycle ergometers for a 10 min period at a pace of their own choosing. In the second practice session, both groups were asked to complete five rounds of 30 s of cycling at peak PO, interspaced by 90 s of active recovery between intervals. ETMs were worn by the experimental group in these practice sessions, while the control group did not wear ETMs.	There were significant differences between the pulmonary function, hematological data, and biomarkers of cardiorespiratory fitness of the experimental group and the control group after the 8-week cycle ergometer HIIT program, in favor of the experimental group.

Table 1 (continued)

Author	Sample Characteristics	Study Design	Intervention	Result
Astorino et al., 2019	Three men and eleven women (age and VO_2max = 27 ± 8 years and 38 ± 4 mL/kg/min, respectively) who perform >150 min/week of exercise in the last 12 months, including resistance training, aerobic exercise, noncompetitive sport, and group exercise, participated in this study.	Experimental	Sessions were held three days/week for three weeks and were performed on the same cycle ergometer. Subjects performed eight 1 min intervals on days 1–3 of training, nine on days 4–6, and ten on days 7–9. Sessions were preceded by a 5 min warm-up at 10% PPO, and intervals were separated by a 75 s active recovery at 10% PPO.	The results of this research show that training HR was associated with the VO_2max response to HIIT, yet dietary intake, sleep duration, and BLa accumulation were not predictive of this response. Overall, these preliminary data suggest that the absolute cardiovascular strain may be a mediator of the adaptive response to interval training.
Cuddy et al., 2019	A cohort (n = 32) of men (n = 16) and women (n = 16) were recruited from the faculty/employee population of a local university and hospital via advertisement through the university website, local community newspaper, and through word-of-mouth.	Experimental	Participants subsequently performed two REHIT testing sessions (i.e., the intense ride) on separate days. At the first testing session, after being connected to the Oxycon Mobile system and Polar F1 heart rate monitor, participants rested quietly for 5 min in a seated position. The last minute of breath-by-breath and heart rate (HR) data were averaged and considered to be the resting metabolic rate (VO_2) and resting HR	The main finding of the present study is that 8 wks of REHIT was safe and elicited more potent, time-efficient improvements in CRF and cardiometabolic health when compared to traditional MICT.
Hurst et al., 2019	Thirty-six adults (50–81 years; 21 male) were assigned via minimisation to either HIT (n = 18) or a no-exercise control group (CON, n = 18) following baseline assessment of leg extensor muscle power, handgrip strength, cardiorespiratory fitness (predicted VO_2max) and health-related quality of life (HRQoL).	Experimental	HIT intervention Participants allocated to HIT completed two instructor-led, combined upper- and lower-body HIT sessions per week for 12-weeks (April–August 2016), performed in groups of two to five participants with 72 h recovery between sessions.	This study reports that demonstrated that 12-weeks of combined upper- and lower-body HIT is an effective method for inducing clinically meaningful improvements in aspects of muscular and cardiorespiratory fitness in adults aged over 50 years.
Simonsson et al., 2023	Participants were recruited through a local newspaper advertisement. Eligible participants were nonexercising adults aged 65 years or older with the ability to undertake a twice-weekly training program for 3 months.	Experimental	For each wave of participants, the study procedure started with baseline assessments, followed by randomization, a 3-month-long exercise intervention (supramaximal HIT or MIT), and subsequent follow-up assessments (3-month follow-up). Detailed	The present study shows that supramaximal HIT with controlled target intensity is a viable exercise program to improve cardiorespiratory fitness and cardiovascular function to a similar extent as MIT, in nonexercising older adults.

the intervention's delivery method, such as using a REHIT or isometric cycle ergometer. Some studies showed significant improvements in cardiorespiratory fitness, while others found no improvement.

Each table study examined how interval training affected cardiorespiratory fitness; however, differences were observed in the sample characteristics, intervention design, and assessed outcomes. Although they share similarities in methodological approach and focus on cardiorespiratory fitness, significant differences in study design and sample populations reflect these studies' diverse approaches and outcomes.

Discussion

Interpretation of Results

The systematic review results indicate that interval training (IT) consistently improves cardiorespiratory endurance across various populations, including sedentary

adults, athletes, and older adults. The research emphasizes that when it comes to improving VO_2max and other cardiorespiratory markers, moderate-intensity continuous training (MICT) is inferior to high-intensity interval training (HIIT). Notably, IT was shown to be particularly effective in populations with lower initial fitness levels, where the magnitude of improvement was more pronounced. A routine that consists of high-intensity exercise followed by relaxation or less intense exercise, which can help the cardiovascular system better use and transport oxygen, may lead to this increase. These results support that interval training can lead to greater physical adaptations than continuous moderate-intensity training. This is part of the practice theory. This finding is also supported by (Jatmiko et al., 2024), who found that vigorous interval training (HIIT) improved aerobic ability better than continuous moderate exercise. However, studies such as (Soares et al., 2021) show that high intensity can increase the risk of injury in people not used to this type of exercise.

Impact on Theory and Practice

The findings of this study make essential contributions to fitness theory and practice. These theoretical results support the idea that HIIT can produce more incredible cardiovascular changes. This is in line with research by Ma et al. (2023), which found that interval training increased VO_2max better than moderate-intensity training. These results imply that interval training is a quick and efficient way to improve cardiovascular fitness. As suggested by (Baker et al., 2020) in the ACSM fitness guidelines, it is essential to consider individual aspects, such as a person's initial fitness level and risk of injury, when implementing a HIIT program.

Social and Ethical Implications

The findings of this study make essential contributions to fitness theory and practice. These theoretical results support the idea that HIIT can produce more incredible cardiovascular changes. This is in line with research by Ma et al. (2023), which found that interval training increased VO_2max better than moderate-intensity training. These results imply that interval training is a quick and efficient way to improve cardiovascular fitness. As suggested by Baker et al. (2020) in the ACSM fitness guidelines, it is essential to consider individual aspects, such as a person's initial fitness level and risk of injury, when implementing a HIIT program.

Suggestions for Future Researchers

Further research should consider several elements to support these findings. Studies with more extensive and diverse populations will be conducted to generalize the results. Long-term research evaluating the impact of interval training over a more extended period is also essential. Additionally, closer monitoring of adherence to exercise protocols would provide more accurate information about how practical interval training is. Further research could also investigate the physiological mechanisms underlying the increases in cardiorespiratory endurance produced by high-interval training (HIIT) and how it compares to other training techniques.

Research Limitations

This study has several limitations that need to be noted. First, the external validity of these findings may be affected by the relatively small sample size; studies with larger samples are required to confirm these results. Second, interval training on cardiorespiratory endurance could not be evaluated in the long term due to the short duration of the study. Differences in participants' adherence to exercise protocols may also impact results. The inability to view each training session live may result in variations in the intensity and volume of training performed by the individuals participating.

Population-Specific Adaptations

Sedentary Adults: In studies such as those by Jung et al. (2020), HIIT interventions significantly improved VO_2max and other markers of cardiovascular health, suggesting that short-term, high-intensity exercise is effective even in populations with low baseline physical activity levels.

Athletes: Research by Abouzeid et al. (2023) demonstrated significant enhancements in pulmonary function and hematological variables after an 8-week HIIT program, emphasizing the benefits of IT for already physically active individuals in further optimizing their cardiorespiratory fitness.

Older Adults: Studies like those conducted by Yang et al. (2023) show that HIIT can be safely implemented in older populations, resulting in substantial improvements in VO_2max and cardiovascular function comparable to those achieved through MICT.

Impact of Exercise Modality and Duration

The analysis found that the effectiveness of IT is influenced by the specific protocol employed, with variations in work-to-rest ratios, session frequency, and overall duration affecting the magnitude of cardiorespiratory improvements. For instance, Songsorn et al. (2023) reported that reduced-exertion high-intensity interval training (REHIT) is particularly time-efficient while yielding significant health benefits.

Biological Mechanisms

Across the studies, it was observed that IT enhances cardiovascular efficiency by improving oxygen utilization and delivery. The data suggest that repeated exposure to high-intensity stimuli prompts more excellent cardiovascular adaptations than continuous moderate exercise, as evidenced by significant VO_2max and cardiac output increases.

Safety and Adherence

While HIIT is effective, it also risks injury if not correctly administered, particularly in untrained individuals. However, when adherence to exercise protocols was closely monitored, as in the study by Astorino et al. (2019), the risk was minimized, and participants safely achieved substantial cardiorespiratory gains.

Comparison with Traditional Training Methods

The findings consistently support the superiority of HIIT over MICT in improving cardiorespiratory fitness. This aligns with the growing literature that endorses IT as a more efficient and effective training modality for clinical and athletic population.

Conclusions

According to this research, interval training can significantly improve cardiorespiratory endurance. These results support the theory that continuous moderate-intensity exercise cannot optimize cardiovascular and metabolic adaptations like high-intensity exercise alternating with rest periods. These results support the idea that HIIT is an excellent technique for improving cardiovascular endurance and aerobic capacity. In other words, these findings offer an effective alternative for those who want to improve their cardiovascular condition in a shorter time. However, it is essential to consider each person's differences when creating this exercise program, especially regarding the risk of injury for those not used to high-intensity training.

Conflict of interest

The authors reported no conflicts of interest.

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Ефективність інтервального тренування щодо підвищення рівня кардіореспіраторної витривалості: Систематичний огляд

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Реферат. Стаття: 8 с., 1 табл., 1 рис., 33 джерела.

Історія питання. Зростання кількості серцево-судинних захворювань зумовило необхідність впровадження ефективних інтервенцій, спрямованих на підвищення рівня кардіореспіраторної витривалості.

Мета дослідження. Мета цього систематичного огляду полягала в оцінці ефективності інтервального тренування (ІТ), зокрема високоінтенсивного інтервального тренування (ВІІТ), щодо підвищення рівня кардіореспіраторної витривалості в різних демографічних групах. ІТ, що характеризуються високоінтенсивними вправами з подальшими періодами відновлення, привертають увагу завдяки своєму потенціалу покращувати ключові показники серцево-судинної системи, як-от максимальний об'єм споживання кисню (VO_2max) та продуктивність серцево-судинної системи.

Матеріали та методи. Проведено комплексний літературний пошук з використанням декількох баз даних згідно з рекомендаціями PRISMA. Із 893 попередньо відібраних статей було визначено вісім досліджень, які відповідали критеріям включення. У вказаних дослідженнях вивчався вплив ІТ, особливо ВІІТ, на кардіореспіраторну витривалість у різних групах населення, включаючи осіб, які ведуть малорухливий спосіб життя, спортсменів і людей похилого віку. В якості основних вимірюваних параметрів були такі показники, як VO_2max і продуктивність серцево-судинної системи.

Результати. Отримані дані вказують на те, що ІТ, зокрема ВІІТ, сприяють послідовному покращенню показників VO_2max та загального стану серцево-судинної системи в різних групах населення. Відзначено перевагу ВІІТ над безперервним тренуванням помірної інтенсивності (БТПІ) у формуванні швидшої адаптації серцево-судинної системи. Незважаючи на свої переваги, висока інтенсивність ІТ вимагає ретельної індивідуалізації з метою зниження ризику травмування, особливо в групах населення з більш низьким початковим рівнем фізичної підготовленості.

Висновки. Представлений огляд дозволяє зробити висновок, що ІТ є ефективним та раціональним за часом методом підвищення рівня кардіореспіраторної витривалості. Його слід розглядати як життєздатний варіант як у клінічних, так і в спортивних популяціях. Однак рекомендується проведення подальших досліджень щодо вивчення довгострокової безпеки ВІІТ у групах високого ризику та поліпшення рівня дотримання вказаних протоколів тренувань.

Ключові слова: інтервальне тренування, кардіореспіраторна витривалість, високоінтенсивне інтервальне тренування, систематичний огляд, VO_2max, здоров'я серцево-судинної системи.

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Review Article

Pencak Silat as a Comprehensive Method of Mental, Physical, and Spiritual Growth: A Systematic Review

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Abstract

Objectives. The study aimed to better understand physical performance by reviewing the literature on the role that Pencak Silat plays in developing elite athletes. The traditional Indonesian martial art Pencak Silat provides a comprehensive method encompassing mental, physical, and spiritual growth.

Materials and methods. The literature regarding Pencak Silat impact on the development of elite athletes was analysed using a PRISMA filter. This study used a systematic evaluation of pertinent literature to determine Pencak Silat impact on mental endurance, motor ability, and physical fitness. The preparation of Pencak Silat athletes for competition through physical conditioning was addressed in articles published between 2019 and 2024. Electronic searches were conducted through Web of Science, PubMed, and Scopus. Having reviewed the literature, all the works that discuss the development of elite athletes in Pencak Silat were compiled.

Results. This study's thorough literature review revealed that Pencak Silat contributes to enhancing the resilience, agility, flexibility, and strength of athletes' bodies. Furthermore, the Pencak Silat concept imparts the courage, discipline, and strategic thinking abilities that are necessary to become exceptional athletes. The results of this study also demonstrate Pencak Silat capacity to achieve a balance between mental and physical attributes, which is crucial for overcoming obstacles in both domestic and international competition. It is anticipated that the study's findings will contribute to a better understanding of Pencak Silat as an all-encompassing and excellent instrument for athlete development.

Conclusions. Pencak Silat is a method of self-development that helps athletes become exceptional in all spheres of their lives — physically, psychologically, and spiritually. It is not just a martial art. Pencak Silat, which emphasizes endurance, mental toughness, and strategy, is an effective instrument for attaining great performance in sports.

Keywords: systematic review, Pencak Silat, physical performance, superior athletes.

Introduction

A martial art called Pencak Silat can be used for self-defence, competitive sports, character development, and other purposes (Guntoro et al., 2023; Nurhidayah et al., 2024; Rahayuni, Taufik, et al., 2023). This study's primary goal is to investigate how Pencak Silat develops elite athletes' physical stamina, motor abilities, and mental toughness. The PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a systematic methodology to efficiently and transparently filter and evaluate scientific literature. It is used in this study to locate and analysed relevant literature.

A traditional martial art known as Pencak Silat originated in Indonesia and other Southeast Asian nations (Mardius et al., 2024; Setiadi et al., 2024). In addition to being a philosophically rich cultural legacy, Pencak Silat has evolved into a competitive sport with international recognition (Karo-Karo et al., 2023; Khotimah et al., 2023). Pencak Silat, one of the sports that can generate exceptional athletes, has grown in popularity since participating in the Asian and SEA Games (Ihsan et al., 2022; Muzakki et al., 2023). Pencak Silat emphasizes combat technical skills within the context

of modern sports, along with requiring a high level of physical fitness, motor skills, and mental toughness. Pencak Silat competitors need to be strong, have quick reactions, and be laser-focused. Additionally, Pencak Silat instils moral values that indirectly support the growth of strong character and integrity, such as self-control, discipline, and respect for the values of opponents.

Few studies thoroughly outline the effects of Pencak Silat on the development of exceptional athletes from many physical, motor, and mental aspects, despite the fact that several studies have been done to investigate the benefits of Pencak Silat in enhancing athletes' abilities. As a result, a more thorough and organized method of examining the body of current literature is required. To give a comprehensive picture of how Pencak Silat shapes elite athletes, the PRISMA approach is the ideal instrument for methodically sifting and analysing pertinent evidence.

Using the PRISMA method, this study seeks to demonstrate Pencak Silat's capacity to develop elite athletes (Haddaway et al., 2022). This study compiles and analyses the studies on Pencak Silat's impact on athletes' physical fitness, motor skills, and mental endurance. This study is anticipated to significantly advance scientific knowledge on how Pencak Silat may develop exceptional athletes for a variety of tournaments, both domestically and internationally, by employing the PRISMA approach.

Materials and Methods

Database and Search Profile

This systematic review includes electronic searches on PubMed, Scopus, and the Web of Science. Terms like "motor skills", "mental resilience", "physical fitness", and "Pencak Silat" are mixed in electronic searches. The search approach's four parts are divided. 450 papers about Pencak Silat and sports were discovered overall using the PRISMA Process during the first identification phase of electronic searches carried out through PubMed, Scopus, and the Web of Science. After removing duplicates, there may still be up to 320 articles. These articles then undergo screening, which is a second stage of filtering in which 170 of the 320 articles are selected based on their abstract and title. After carefully evaluating the methodology and research findings, only 120 articles are relevant to the topic; the remaining 65 meet the eligibility criteria. During the fourth phase, known as inclusion, the final review contained up to thirty articles that met the notability requirements using the PEDro scale, which is available online for free. These articles have been translated into seven languages in Figure 1.

Out of 450 publications that adhered to the PRISMA requirements, 30 articles were chosen in total during the identification, screening, conformity, and inclusion phases (Page et al., 2021). The flow chart (Figure 1) shows this procedure. The bibliometric analysis considered the following variables: the following five variables determine the yearly trend of papers produced between 2019-2024: The first author's institution's publication distribution, the total number of authors, the type of research (different, experimental, descriptive, or correlational), the average number of citations per article, and the field of study (motor skills, mental resilience, physical fitness, Pencak Silat, other,

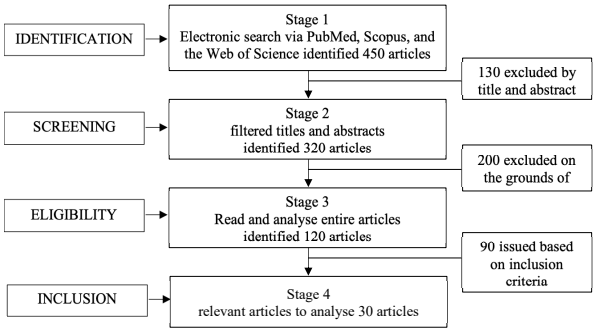

Fig. 1. An illustration of the flow of the search process

or mixed) are all taken into consideration. Table 1 displays the general inclusion and exclusion criteria.

Table 1. Superior athletes are formed by a Pencak Silat's inclusion and exclusion standards

Inclusion Criteria	Exclusive Criteria
The 2019–2024 study, which looked at how Pencak Silat affected athletes' physical fitness, motor abilities, or mental endurance, was published	The study were studies that did not address Pencak Silat or that did not look at different facets of athletes' physical and mental conditioning
Population	Pencak Silat athletes
Intervention	Core training lasting at least four weeks
Comparison	More than two groups
Results	Performa condition athlete elite
Design of research	Physical fitness, motor skills, or mental resilience

A thorough explanation of each inclusion criterion, including population, comparison, study methodology, intervention, and results, is given in Table 1. The study's primary objective was to ascertain how Pencak Silat enhances athletes' physical performance. If the literature satisfies the following criteria, it will be incorporated into the study.

1. Population: Pencak Silat athletes with a range of physical performance levels make up the test subjects. Pencak Silat athletes' range in physical performance from novices to school levels, province levels, and national levels. Their physical performance is classified into three categories: physical fitness, motor skills, and mental endurance.
2. Intervention: Studies have demonstrated that athletes' performance is not considerably enhanced by training periods less than four weeks (Yulanda & Jariono, 2023; Burhanuddin et al., 2023). Therefore, the intervention entails conducting physical fitness, motor skills, or mental endurance experiments for longer than four weeks.
3. Comparison: A minimum of two groups were involved, and as a baseline for comparison, the groups for physical fitness, motor skills, and mental endurance were compared with other training or with no training (Usra et al., 2024; Wahyuni et al., 2024).

4. Results: The primary focus of the results is the athletes from Pencak Silat and their performance. The study mainly focuses on elements of Pencak Silat performance characteristics, such as mental endurance, motor skills, and physical fitness. The following is the definition of skill performance. Pencak Silat athletes are categorized into numerous skill sets based on their abilities, including physical, mental, technical, and tactical talents. Performance indicators of elite Pencak Silat athletes: (1) physical performance: strength, speed, endurance, agility, flexibility, and body composition (Gusciglio & Morin, 2023; Kudryavtsev et al., 2023; Lubis et al., 2022; Teo et al., 2022); (2) mental performance: concentration, motivation, confidence, emotional control, and mental flexibility; (3) Technique performance: movement quality, movement variation, coordination, strength of moves, and use of force (Carvalho et al., 2023; Cid-Calfucura et al., 2023; Folhes et al., 2023; Niewczas et al., 2023); and (4) tactical performance: opponent analysis, decision-making, tactical adjustment, use of distance, use of time (Anastasiou et al., 2024; Martínez-Aranda et al., 2023; Rydzik et al., 2024). However, some of the elements of Pencak Silat's physical performance include agility, flexibility, stability, power, speed, coordination, strength, and balance.
5. Research design: The randomized controlled trials are examined in this review.

Methodological evaluation of quality

The quality of the papers under examination was assessed using eleven PEDros (Physiotherapy Evidence Database) criteria, and their methodological quality was also evaluated. Excellent articles assist readers in overcoming obstacles like time constraints and inadequate critical thinking abilities and make it simpler for them to incorporate high-quality clinical research into clinical practice. According to Moseley, articles with a methodological quality score of eight to eleven are deemed to have high quality, those with a score of four to seven are considered average, and those with a score of four or lower are not examined. Clinical practice guidelines and systematic reviews are not evaluated (Moseley et al., 2020).

Results

Number of Results Reviewed

Electronic searches of PubMed, Scopus, and the Web of Science are conducted using the PRISMA Process. The figure below displays the total number of publications for the chosen period as well as the publishing year. These studies examine how Pencak Silat practices affect physical fitness, mental toughness, and motor skills (Table 2).

Figure 2 illustrates how the quantity of publications has changed across various time periods. First, from 2019 (17 articles), 2020 (32 articles), 2021 (61 articles), 2022 (85 articles), 2023 (100 articles), and 2024 (155 articles), there has been a discernible increase in the amount of research produced. The table above illustrates how biomechanical analysis, which is applicable to Pencak Silat techniques, is

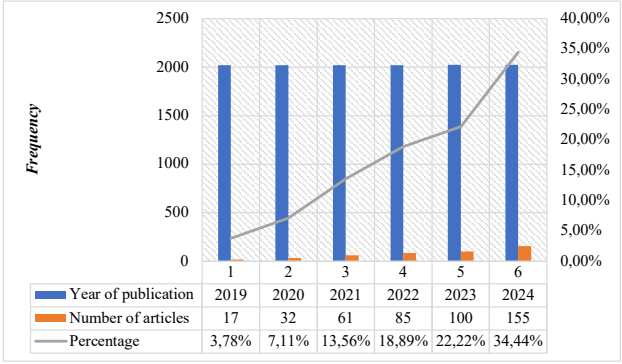

Fig. 2. An increase in the annual number of publications

described in the literature. There are thirty studies in this review. Both art trends and research pertaining to fighting tactics are included. Physical performance, exercise programs, motor skills, physical fitness, and mental stamina.

Exercise Significance Results

Regardless of gender, age, professional level, rookie or expert athletes, or training style, the 30 research that were selected and examined indicated a significant benefit of Pencak Silat training on mental endurance, motor ability, and physical fitness.

Table 2 demonstrates how 30 authors used a random method to enhance the physical attributes of each sport, as well as an overview of the sports examined to guarantee the randomness of each research variable to contribute to the study's findings. The authors used experimental research approaches, surveys, literature reviews, and related research. The population's characteristics were the main topic of discussion in a literature review that examined thirty prior research. The population is typically made up of people of different ages, genders, and skill levels who are sports, students, or those with certain medical concerns. Establishing the demographic is crucial for maintaining consistency in the results analysis and the research's applicability to the intended audience.

In terms of study design, the internal validity and methodological quality of the intervention study are frequently evaluated through the use of the PEDro scale, a research quality assessment tool. This scale evaluates a number of factors, including control, blinding of participants and researchers, and randomization. The majority of the thirty studies that were analysed used experimental and quasi-experimental designs, and the range of PEDro scores (5–10) was considered moderate to high. In the context of the larger body of literature, a study with a high PEDro score is thought to have a robust methodology, good control, and little chance of bias, which increases the validity and reliability of the findings. The features of the research examined in the review and meta-analysis are outlined in Table 3.

Discussion

The study's findings demonstrate that Pencak Silat significantly affects athletes' growth on both a physical and mental level. Pencak Silat enhances a number of physical

Table 2. Population, study design PEDro scale

Study	PEDro scale											
	1	2	3	4	5	6	7	8	9	10	11	
	Qualification standards	At random distribution	Disguise of allocation	Baseline comparability	Participants who are blind	Assessor without sight	Therapist for the Blind	Observation	Goal to handle analysis	Comparisons between groups	Variability in point measures	Total
Anastasiou et al. (2024)	1	1	0	1	0	0	0	1	0	0	1	5
Barley & Harms (2024)	1	1	0	1	0	0	0	1	0	1	1	6
Hausen et al. (2024)	1	1	0	1	0	0	0	1	0	1	1	6
Lubis et al. (2024)	1	1	0	1	0	0	0	1	0	1	1	6
Mulia et al. (2024)	1	1	0	1	0	0	0	1	0	1	1	6
Laurin (2024)	1	1	0	1	0	0	0	1	0	1	1	6
Noonan-holohan et al. (2024)	1	0	0	1	0	0	0	1	0	1	1	5
Sulfa et al. (2024)	1	1	0	1	0	0	0	1	0	0	1	5
Jariono et al. (2024)	1	1	0	1	0	0	0	1	0	1	0	5
Cid-Calfucura et al. (2023)	1	0	0	1	0	0	0	1	0	1	1	5
Mojtahedi et al. (2023)	1	1	0	1	0	0	0	1	0	0	1	5
Osipov et al. (2023)	1	1	0	1	0	0	0	1	0	0	1	5
Antonietto (2023)	1	1	0	1	0	0	0	1	0	1	1	6
Korobeynikov et al. (2023)	1	1	0	1	0	0	0	1	0	0	1	5
Francisco et al. (2023)	1	1	0	1	0	0	0	1	0	1	1	6
Baranauskas & Stukas (2022)	1	1	0	1	0	0	0	1	0	1	1	6
Delleli et al. (2022)	1	1	0	1	0	0	0	1	0	1	1	6
Fernando et al. (2022)	1	1	0	1	0	0	0	1	0	0	1	5
Mcclung et al. (2022)	1	1	0	1	0	0	0	1	0	1	1	6
Gürsoy & Canli (2021)	1	1	0	1	0	0	0	1	0	1	1	6
Fidan (2021)	1	1	0	1	0	0	0	1	0	1	1	6
Thomas et al. (2021)	1	1	0	1	0	0	0	1	0	1	1	6
Ouergui et al. (2021)	1	1	0	1	0	0	0	1	0	1	1	6
Chycki et al. (2021)	1	0	0	1	0	0	0	1	0	1	1	5
Ziemba et al. (2020)	1	1	0	1	0	0	0	1	0	0	1	5
Kostrzewa et al. (2020)	1	1	0	1	0	0	0	1	0	1	0	5
Lane et al. (2020)	1	0	0	1	0	0	0	1	0	1	1	5
Kłys et al. (2020)	1	1	0	1	0	0	0	1	0	0	1	5
Russo & Ottoboni (2019)	1	1	0	1	0	0	0	1	0	0	1	5
Zubac et al. (2019)	1	1	0	1	0	0	0	1	0	1	1	6

Note: has a thorough explanation for every item on the PEDro scale (https://pedro.org.au/wp-content/uploads/PEDro_scale.pdf)

Tabel 3. Features of the research that were examined for the review and meta-analysis

Author, Year	Variable	Method index	Sig.(p)
Anastasiou et al. (2024)	Physiological, Psychological and Injury Risk Determinants	A Systematic Review	Sig.
Barley & Harms (2024)	Combat Sports and Their Connection to Total Competitive Success	Various Approaches to Training, Losing, and Winning	Sig.
Hausen et al. (2024)	Qualities of Combat Performance and Physical Capabilities	A maximal graded test exercise (visit 1), resting metabolic rate, anthropometric assessment, blood samples obtained prior to, during, and following the conflict (see 2), and a free combat simulation (3 × 3 min R, 1-minute rest) were all included in the evaluation.	Sig.
Lubis et al. (2024)	Strength, power ratio, and kicking velocity	Impact of plyometric, functional, and interval trainings lasting six weeks	Sig.
Mulia et al. (2024)	Bone mass, muscle mass, and body fat percentage	Correlation Analysis	Sig.
Laurin (2024)	Anaerobic Performance and Competitive Experience	quantitative in character and employs a descriptive-correlational methodology based on a quasi-experimental observational design	Sig.
Noonan-holohan et al. (2024)	The psychological factors that influence weight-making in sports with weight categories	A narrative review	Sig.
Sulfa et al. (2024)	Pencak Silat model for teaching response speed	Study Experimental	Sig.
Jariono et al. (2024)	Training Techniques for Physical Activity and Physical Condition	A Systematic Review	Sig.
Cid-Calfucura et al. (2023)	Strength Training for Enhancing Physical Fitness	A Systematic Review	Sig.
Mojtahedi et al. (2023)	The Value of Mental Hardiness	Examine Combat Sport Competition Anxiety	Sig.
Osipov et al. (2023)	Athletic Capabilities	Intervention with Functional Training	Sig.
Antonietto (2023)	Technical-tactical strategies that result in victory	Study Comparted	Sig.
Korobeynikov et al. (2023)	Specialized working capacity and cognitive functions	Study descriptive	Sig.
Francisco et al. (2023)	Relationships, roles, and violent behaviour	This research uses a combination of methodologies	Sig.
Baranauskas & Stukas (2022)	Loss of Weight and Body Composition	This cross-sectional, non-experimental study	Sig.
Delleli et al. (2022)	Physical Performance, Combat Sports: Technical-Tactical Skills, Perceived Exertion, Physiological Responses, and Physical Performance	A Comprehensive Examination and Meta-Analysis	Sig.
Fernando et al. (2022)	Strength Training-Related Hypertrophy Response to Range of Motion	A New Method for Interpreting the Results	Sig.
Mcclung et al. (2022)	Characterization, both physiological and physical	Human Institutional Review Board, Medical Research and Development Command (Fort Detrick, MD)	Sig.
Gürsoy & Canli (2021)	performance traits unique to motor competences, athletic talents, and anthropometric traits	This research uses a combination of methodologies	Sig.
Fidan (2021)	Performance of the Upper Extremities	The creation of a training and assessment system through research	Sig.

Table 3 (continued)

Author, Year	Variable	Method index	Sig.(p)
Thomas et al. (2021)	The Relationship Between Female Combat Sport Athlete Triad and Weight Loss	Study correlation	Sig.
Ouergui et al. (2021)	Physical Fitness	Study descriptive	Sig.
Chycki et al. (2021)	Improves anaerobic and cognitive performance	Study Experimental	Sig.
Ziemba et al. (2020)	Hormonal Profile a Combat Sports Performance	Study descriptive	Sig.
Kostrzewa et al. (2020)	Predictors of Sports Performance	Multidimensional Regression Models	Sig.
Lane et al. (2020)	Determinants of success by decision, knockout or submission	Perceived and actual fighting ability	Sig.
Kłys et al. (2020)	Performance and technical-tactical variables	Optimization of predictors	Sig.
Russo & Ottoboni (2019)	The perceptual – Cognitive skills	A systematic review	Sig.
Zubac et al. (2019)	Fluid balance and hydration status	A meta-analysis and systematic review of both controlled and uncontrolled studies	Sig.

fitness components that are critical for athletic success. Pencak Silat benefits athletes psychologically by fostering the mental toughness and self-control necessary for success in competition. Pencak Silat is more than simply a sport; it's a tool for personal growth as well, as it fosters the development of strong character.

The results of a PRISMA method-assisted literature study show that Pencak Silat significantly influences the development of motor skills, mental toughness, and physical fitness, shaping athletes into elite performers. Every aspect examined in the literature demonstrates that Pencak Silat is a sophisticated and all-encompassing sport that emphasizes both ideal physical and mental development as well as technical fighting skills. The discussion of significant elements uncovered by the literature review is provided below.

Pencak Silat's Impact on Physical Fitness

Almost every muscle in the body must be used during intense Pencak Silat training, which also involves several physiological systems such the cardiovascular system, skeletal muscles, and flexibility (Nurhidayah et al., 2024). Pencak Silat can enhance physical fitness elements like strength, endurance, flexibility, and body coordination, according to the research that was examined (Brechney et al., 2022). Kicks, punches, and other movements in Pencak Silat entail both static and dynamic muscle contractions, which eventually result in an increase in muscle strength (Purnamasari et al., 2022).

Furthermore, studies indicate that Pencak Silat exercises can improve both anaerobic and aerobic ability. Regular Pencak Silat training for eight to twelve weeks has been shown in several studies to raise VO_2max, a crucial measure of cardiovascular fitness. Ensuring athletes to endure extended matches without developing notable physical degeneration is crucial.

Pencak Silat exercise promotes better fitness psychologically by fostering traits like discipline, self-control, and self-confidence in addition to its physical benefits (Zulfa & Hanief, 2022). These elements have the potential to motivate people to continue exercising, which will help them become more physically fit overall..

Development of Motor Skills

Pencak Silat emphasizes not only physical conditioning but also the development of strong motor abilities. Stable balance and good upper-lower limb coordination are necessary for Pencak Silat manoeuvres. Pencak Silat exercises improve both fine and gross motor skills, which enhances an athlete's capacity to react to external cues during competition, according to a review of the literature.

Hand-eye coordination, balance, and accuracy in both attacking and defending are among the motor abilities that have improved (Burhanuddin et al., 2023). According to the study, after participating in a lengthy training program, Pencak Silat athletes had a considerable improvement in their coordination and response time (Rahayuni, Maulidiya, et al., 2023). This aids them in handling fast-paced match scenarios that call for quick decisions.

Pencak Silat's Improvement of Specific Motor Skills. Elite Pencak Silat athletes need to possess precise, quick, and potent offensive abilities (Hariono et al., 2024). Exercise regimens like Shadow Fighting or repetitive punch and kick exercises (repetition techniques) might enhance the capacity to execute movements (Mardius et al., 2024). Skills related to defence: quick reflexes and coordination are necessary for defensive manoeuvres such avoiding, parrying, and blocking (Nugroho et al., 2021). The study's findings can be used to explain how athletes can improve their ability to react to opponent strikes by engaging in reaction training using a variety of tactile and visual stimuli.

Mental Stability and Self-Restraint

The development of the mind is given equal weight with the physical side of Pencak Silat. Pencak Silat demands intense discipline, emotional restraint, and focused attention. In comparison to players from other sports, the study's findings indicate that Pencak Silat competitors are more mentally capable of handling psychological pressure.

Because athletes need to be able to handle pressure from their surroundings and handle stress, tension, and anxiety, mental resilience is crucial in the competitive setting (Rustiyanti et al., 2023). Athletes who practice Pencak Silat learn emotional self-control, which helps them remain composed under pressure and make wise choices throughout a game (Sulfa et al., 2023). Pencak Silat athletes are more psychologically resilient due to their high mental resilience, which helps them overcome a variety of obstacles during their sports careers.

The Significance of Mental Hardiness in Handling Pressure During a Match. The capacity of athletes to maintain focus, self-assurance, and excitement in the face of adversity is known as mental toughness or resilience (Kiliç, 2021). According to (Low et al., 2023), athletes with high mental resilience are typically better equipped to handle pressure from rivals, officials, spectators, and shifting competition conditions. Verdolini et al., (2021), reported that the study yielded specific findings regarding the ways in which sportsmen dealt with stress, anxiety, and outside pressure during games. These strategies could be assessed using in-depth interviews or mental resilience assessment tools. Elite athletes employ effective mental strategies for the development of mental resilience, such as positive self-talk, visualization, meditation, or relaxation techniques (Ungar & Theron, 2019). According to Verdolini et al., (2021) According to.

With this talk, the research can offer a thorough understanding of the significance of mental toughness and self-control development for elite Pencak Silat athletes, as well as suggestions for the use of more efficient mental development techniques in athlete coaching programs.

The development of athletes' morality and character

Pencak Silat emphasizes significant spiritual and moral qualities, such as discipline, humility, courtesy, and respect, in addition to physical and mental aspects. The Pencak Silat ideology, which teaches athletes to respect opponents and maintain integrity in competition, is a reflection of these ideals. Knowledge on the development of character via Pencak Silat demonstrates how athletes acquire strong discipline, dedication to training, and morality in handling wins and losses.

Athletes' personalities are shaped by the moral principles found in Pencak Silat, making them not only more gifted intellectually and physically but also more responsible and sportsmanlike (Schiff, 2022). According to a survey of the literature, Pencak Silat helps develop athletes who are more moral, disciplined, and capable of managing their emotions under pressure. To guarantee that athletes can serve as positive role models for other athletes, fans, and society at large, character development and ethics are crucial. Character development programs, which emphasize the practice of discipline, honesty, and accountability, have a significant part in moulding athletes with high integrity, according to Petróczi's research on the subject (Petróczi et al., 2022). Strong-character athletes typically exhibit sportsmanship, integrity during competition, and respect for officials, coaches, and other teams (Loyens et al., 2022).

Integrating Moral Principles into the Training Process: Research (Zhang et al., 2023), demonstrates how moral principles including justice, empathy, and honesty are included into athletes' routine training (Jariono et al., 2024). The Value of Character Development via a Holistic Approach: Athletes' character development must be approached from a holistic perspective, taking into account their mental, emotional, and physical well-being (Rusilowati & Wahyudi, 2020). Reflection sessions, moral values conversations, and regular assessments of attitudes and behaviours are all common components of an effective character development program (Karimah et al., 2021).

Conclusions

According to a thorough literature analysis, numerous training plans have been developed to enhance the physical attributes of Pencak Silat players, such as balance, strength, muscle power, speed and acceleration, flexibility, agility, and explosive power.

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Conflict of Interest

The authors reported no conflicts of interest.

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Пенчак Сілат як комплексний метод ментального, фізичного та духовного зростання: Систематичний огляд

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

Реферат. Стаття: 11 с., 3 табл., 2 рис., 73 джерела.

Мета дослідження. Мета дослідження полягала в поліпшенні розуміння фізичної продуктивності шляхом огляду літератури щодо ролі, яку відіграє Пенчак Сілат у контексті розвитку елітних спортсменів. Традиційне індонезійське бойове мистецтво Пенчак Сілат містить комплексний метод, що охоплює ментальне, фізичне та духовне зростання.

Матеріали та методи. Аналіз літературних джерел щодо впливу Пенчак Сілат на розвиток елітних спортсменів проводився за допомогою методики фільтрування PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) – переважні елементи звітування для систематичних оглядів і метааналізів. У цьому дослідженні використовувалася систематична оцінка релевантної літератури з метою визначення впливу Пенчак Сілат на рівень ментальної витривалості, рухових здібностей і фізичної підготовленості. У статтях, опублікованих між 2019 і 2024 роками, розглядалися питання підготовки спортсменів з Пенчак Сілат до змагань за допомогою фізичної підготовки. Електронний пошук проводився шляхом використання таких наукометричних баз даних: Web of Science, PubMed та Scopus. Провівши аналіз літератури, складено перелік усіх робіт, в яких обговорювалися аспекти розвитку елітних спортсменів з Пенчак Сілат.

Результати. Ґрунтовний огляд літератури показав, що Пенчак Сілат сприяє підвищенню показників витривалості, спритності, гнучкості та силових якостей організму спортсменів. Крім того, концепція Пенчак Сілат розвиває сміливість, дисципліну та здібності до стратегічного мислення, які є необхідними чинниками для становлення успішних спортсменів. Результати цього дослідження також демонструють здатність Пенчак Сілат досягати балансу між розумовими та фізичними якостями, що має ключове значення для подолання труднощів як на внутрішніх, так і на міжнародних змаганнях. Передбачається, що результати дослідження сприятимуть кращому розумінню Пенчак Сілат як комплексного та відмінного інструменту розвитку спортсменів.

Висновки. Пенчак Сілат є методом саморозвитку, який допомагає спортсменам досягти виняткових результатів у всіх сферах життя: фізичній, психологічній та духовній. Адже зазначений вид спорту є не лише бойовим мистецтвом. Пенчак Сілат, в якому акцент робиться на витривалості, ментальній стійкості та стратегії, є ефективним інструментом досягнення високих результатів у спорті.

Ключові слова: систематичний огляд, Пенчак Сілат, фізична продуктивність, спортсмени високої кваліфікації.

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Інструкції для рецензентів

Цей журнал є рецензованим. Оригінальні наукові статті, повідомлення та огляди надсилаються для розгляду щонайменше двом рецензентам. Рецензування відбувається за подвійною сліпою схемою. Статті, які мають позитивні оцінки приймаються до публікації. Редакція журналу залишає за собою право внести зміни до тексту, щоб відповідати стандартам стилю журналу та мови.

Головний редактор журналу визначає відповідність статті профілю журналу, вимогам до оформлення і направляє її на рецензування фахівцям, що мають найбільш близьку до теми статті наукову спеціалізацію.

У кожній статті у процесі рецензування завжди розглядаються:

- етичні аспекти;
- оригінальність твору;
- важливість інформації;
- чіткість та зрозумілість тексту;
- доцільність використання методів дослідження;
- інтерпретація результатів;
- обґрунтованість висновків.

Типовий період, необхідний для проведення рецензування складає 4 тижні.

Етичні принципи у діяльності рецензента

Рецензент здійснює неупереджене фахове рецензування поданої до розгляду статті на основі таких принципів:

- рецензент повинен поважати інтелектуальну власність авторів, і розглядати рукопис статті, що надійшов на рецензування, як конфіденційний, який не можна передавати для ознайомлення або обговорення третім особам, які не мають на це повноважень від редакції;
- рецензент зобов'язаний давати об'єктивну оцінку викладеним результатам дослідження, персональна критика автора неприпустима;
- у разі конфлікту інтересів з автором, слід повідомити про це редактора з проханням виключити його з процесу рецензування даної статті.

Політика щодо плагіату

Редакція журналу вважає неприйнятним наявність плагіату в статтях (оприлюднення у письмовій або електронній формі наукових результатів, отриманих та оприлюднених іншими особами, як результатів власного дослідження та/або відтворення опублікованих текстів інших авторів без відповідного посилання).

У статтях не допускається:

- копіювання та оприлюднення виконаної іншим автором роботи як своєї;
- дослівне копіювання фрагментів тексту (від фрази до набору речень) без належного оформлення цитування;
- внесення незначних правок у скопійований матеріал (переформулювання речень, зміна порядку слів в них тощо) та без належного оформлення цитування;
- переказ своїми словами чужих думок, ідей або тексту без належного оформлення посилання на джерело.

Обов'язковим є посилання на власні, раніше опубліковані роботи.

Редакція відхиляє поданий рукопис, якщо він містить запозичення з інших публікацій без належного цитування, та може скасувати публікацію за скаргою в плагіаті.

Як підготувати рецензію?

Попередній огляд

Перш ніж прийняти або відхилити запрошення на рецензування, розгляньте такі питання:

- Чи відповідає стаття вашій спеціалізації? Приймайте запрошення, якщо ви впевнені, що можете надати якісний огляд.
- Чи є у вас конфлікт інтересів? Дайте відповідь на це питання.
- Чи є у вас час? Рецензування може вимагати багато часу – перш ніж приймати запрошення, переконайтеся, що ви можете виконати роботу до вказаного строку.

Дайте відповідь на запрошення, як тільки ви зможете. Затримка відповіді сповільнює процес розгляду матеріалу. Якщо ви відхилите запрошення, за можливості, надайте пропозиції альтернативних рецензентів.

Якщо ви приймаєте запрошення, то ви повинні розглядати матеріали як конфіденційні документи. Це означає, що ви не можете поділитися ними з кимнебудь без попереднього дозволу редактора. Оскільки експертний огляд є конфіденційним, ви також не повинні передавати інформацію про рецензію будькому без дозволу редакторів та авторів.

По-перше, прочитайте статтю, а потім зробіть перерву. Розгляньте статтю з власної точки зору. Переконайтеся, що ви знаєте критерії оцінки статті, запропоновані журналом.

Огляд

Ваша рецензія допоможе редакторові вирішити, чи слід публікувати статтю. Важливою є ваша загальна думка та висновки про статтю. Ваші коментарі повинні бути доброзичливими та конструктивними, а також

не містити жодних особистих зауважень чи особистих даних, включаючи ваше ім'я.

Важливо надати інформацію про будь-які наявні недоліки. Ви повинні пояснити ваше судження, щоб як редактори, так і автори, могли повною мірою зрозуміти ваші коментарі.

Контрольний список

Оцініть такі аспекти статті: (якщо відповідь «Ні», будь ласка, за можливості, запропонуйте покращення)

- Чи заголовок точно відображає зміст тексту?
- Чи чітко зазначено мету?
- Чи суттєвий внесок у розробку зазначеної проблеми робиться цією статтею?
- Чи розкриває стаття мету дослідження?
- Чи логічно викладений матеріал статті?
- Чи висвітлена в анотації суть статті, анотація є інформативною та лаконічною?
- Чи висновки автора адекватні експериментальному матеріалу?

Надайте конкретні коментарі та пропозиції, зокрема, щодо оформлення, назви, опису, вступу, гіпотези та/або предмету дослідження, матеріалів і методів, статистичної обробки матеріалів, результатів, обговорення, висновків, мови та посилань.

Якщо ви вбачаєте прояви академічної недоброчесної, обговоріть свої припущення з редактором, надайте якомога докладнішу інформацію.

Ваша рекомендація

Коли ви даєте рекомендацію, то обираєте одну з категорій, які використовуються для класифікації статті:

- прийняти подання;
- необхідні виправлення;
- необхідне додаткове рецензування;
- до іншого видання;
- відхилити подання.

Остаточне рішення

Головний редактор вирішує, чи прийняти чи відхилити статтю. Редактор, перш ніж прийняти рішення, зважить всі погляди та може зажадати третю думку або попросити автора переглянути документ. Видавнича система надає користувачам повідомлення про остаточне рішення.

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