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Теорія та методика фізичного виховання

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Original Scientific Article

Anaerobic Soccer Training Model: Enhancing Soccer Players' Performance through a Combination of Repeated Sprints and 4 vs 4 Games

I Dewa Made Aryananda Wijaya Kusuma[1ABCD], Nining Widyah Kusnanik[1ACD], Bayu Agung Pramono[1ACD], Adi Pranoto[1ACD], Yanyong Phanpheng[2ACD], Indra Himawan Susanto[1BCD], Dewa Ayu Praba Amustikarani[1BCD], Waristra Tyo Nirwansyah[1BCD] and Muhammad Bagus Firzam Bharlaman[1BCD]

[1]Universitas Negeri Surabaya
[2]Loei Rajabhat University

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

Corresponding Author: I Dewa Made Aryananda Wijaya Kusuma, e-mail: dewawijaya@unesa.ac.id
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Abstract

Objectives. The Anaerobic Soccer Training (AnST) model was designed to increase variation in soccer training programs by implementing a game-based approach to matching characteristics. This study aimed to evaluate the effectiveness of the training model in improving soccer players' anaerobic abilities.

Materials and methods. The research method used was the ADDIE model consisting of five integrated phases: Analysis, Design, Development, Implementation, and Evaluation. Eighty-two soccer players from the UNESA male student activity unit were involved in this study, with 20 samples taken using random sampling techniques. Sample characteristics included the following data: age 20.05 ± 0.69 years, height 165.85 ± 5.00 cm, weight 62.08 ± 6.82 kg, and BMI 22.54 ± 1.98. The intervention was carried out over a four-week period, with a frequency of three times a week. The Aiken's V test was used to analyze the assessment data from three expert judgments, followed by percentage analysis for content validity. The normality test was conducted using the Shapiro-Wilk test, while the mean difference was analyzed using the paired sample t-test.

Results. The results showed that in variables for peak power (.001), mean power (.000), fatigue index (.013), Lactate Week (LW) 1-2 (.020) and LW1-3 (.038), notable differences with significance values below 0.05 were observed. In contrast, LW1-4 (.631) did not demonstrate significant differences. Overall, the development of the AnST model successfully improved the anaerobic ability of players, as evidenced by an increase in peak power, mean power, and a decrease in the fatigue index.

Conclusions. These findings indicate that this training model is effective in enhancing the anaerobic performance in soccer players.

Keywords: anaerobic, soccer training, repeat sprint, small sided games.

Introduction

Soccer requires high physical ability with moderate to high-speed running movements in a ninety-minute match duration, with match intensity reaching 90 % of the maximum heart rate (Mendez-Villanueva et al., 2013; Rebelo et al., 2014). When viewed from the perspective of using its energy system, McArdle et al. (2014) concluded that players need 10 % energy through the phosphocreatine system, 70 % anaerobic glycolysis, and 20 % aerobic glycolysis. In addition, based on previous research, players cover a distance of up to 13 km in the match and perform sprinting, acceleration, deceleration, and changes of direction interspersed with short recovery periods (Beato & Jamil, 2018). A soccer player performs a sprint action at a speed of >19.7 km/h for 645.71 meters

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(Wehbe et al., 2014), 19.8-25.2 km/h for 771 meters (Carling et al., 2016), 21.1-24.0 km/h for 518.25 meters (Miñano-Espin et al., 2017), and 19.8-25.1 km/h for 617.72 meters (Modric et al., 2019). The number of running frequencies in one match is 33 times (Chmura et al., 2017) and 31 times (Miñano-Espin et al., 2017). If we look at the data, soccer requires very complex training with a dominant need for anaerobic glycolysis. The irony on the field is that coaches tend not to pay attention to these needs, resulting in less-than-optimal performance due to the lack of information on specific physical training models applied to soccer. Based on previous research, popular anaerobic training studies include High-Intensity Interval Training (HIIT) (Faude et al., 2013), Speed Endurance Training (SET) (Iaia et al., 2015), and Repeat Sprint Training (RST) (Beato et al., 2019). Although these exercises are practical in increasing players' anaerobic abilities, in their implementation, there is no information that these exercises are by the needs of the game, especially in terms of the frequency and distance of sprints in one match. In addition, physical training must also involve elements of technique and tactics (Clemente et al., 2022); this is in line with previous systematic review studies, which concluded that a holistic approach positively impacts training (Kusuma et al., 2024). According to Izquierdo et al. (2023), coaches should ideally develop a training program that suits the needs of the competition.

The solution that can be adopted is to develop the Anaerobic Soccer Training (AnST) model. The development adopts the theory of Speed Endurance Training Maintenance (SET-M) Long Intervals with an intensity of 50-80 %, duration of 15-90 seconds, ratio of 1:1-1:3, and repetitions of 6-12 (Hostrup & Bangsbo, 2023). This approach combines elements of high-intensity speed training with elements of technique and tactics in the match, in line with research (M. Oliva-Lozano et al., 2023), which found that repeated sprint ability is needed in soccer games. In more detail, the load refers to the need for repeated sprints in the match, namely the average total running distance (> 19.7 km/h) = 638.17 m. The training intensity used in this exercise is classified as high intensity using the anaerobic lactate acid energy system. Several studies have identified that soccer players require energy from various sources, including the phosphocreatine system, anaerobic glycolysis, and aerobic glycolysis (Coratella et al., 2016; Hill-Haas et al., 2011; McArdle et al., 2014; Wong et al., 2012). In addition, the importance of repeated sprinting ability and high running frequency during matches has been emphasized in previous literature. In addition, physical training such as HIIT, SET, and RST have been studied and proven effective in improving the physical abilities of soccer players. However, they have not fully met the needs of matches, especially in terms of sprint frequency and distance.

To address the gap between existing training models and the specific match needs in soccer, this study attempts to develop a new model called Anaerobic Soccer Training (AnST). One of the unique features of the AnST model is its more specific approach to the needs of repeated sprinting in soccer matches, which is reflected in training loads such as the total average running distance at high speed, the number of sprints, and the duration of sprints without leaving out the technical and tactical components. Thus, the AnST model offers a more focused and relevant solution to improve the physical abilities of soccer players according to match requirements.

Materials and Methods

Study Participants

82 UNESA male student soccer players comprised the population in this study, and 20 players were taken as samples. The sample was taken using a random sampling technique. The characteristics of the sample were 20.05 ± 0.69 years old, 165.85 ± 5.00 cm tall, 62.08 ± 6.82 kg in weight, and 22.54 ± 1.98 in BMI. This trial was implemented for four weeks with a frequency of three times a week.

Study Organization

This study uses the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) Method (Branch, 2009). The analysis stage is marked by identifying problems in the field, where a lack of a holistic soccer training program combines technical, physical, and tactical elements. In the Design stage, researchers began to design training called AnST. This training combines the SET-M Long Interval concept with tactical training elements. In the Development stage, researchers conducted a Focus Group Discussion (FGD) to test the validity of the design with the objectives to be achieved and obtain input from expert judgment. The validity test involves three expert judgments: soccer, physical, and game experts. This stage aims to ensure that the product being developed meets the objectives and is based on the characteristics of soccer before being tested. In the implementation stage, researchers conducted a trial where the trial was carried out with a sample size of 20 people. The last stage is evaluation, which is carried out to improve certain elements, adjust the intensity of training, add variations, or make other changes based on feedback and evaluation results. The test instrument used at this stage is RAST to determine anaerobic ability—a questionnaire to test the validity of the product. In addition, heart rate and lactate monitoring instruments can be used from a physiological perspective.

Statistical Analysis

Validity test analysis in developing the AnST model uses quantitative descriptive analysis. The Aiken'V test is used to analyze the assessment data of three expert judgments. After the content validity test is declared valid, the assessment data of three expert judgments are analyzed using percentages to determine the feasibility of the product being developed. The normality test in this study uses the Shapiro-Wilk test, while the average difference test uses the paired sample t-test.

Training Program

This AnST exercise uses the Speed Endurance Training and Game (SSG) approach with a 1:1 interval. The SSG area is 20x20 meters, and each player will sprint back and forth with a distance of 5 meters, 10 meters, and 15 meters before starting the SSG. The total sprint taken in one repetition is 60 meters, with an estimated time for a 5-meter back-and-forth sprint of around 2-3 seconds, a 10-meter back-and-

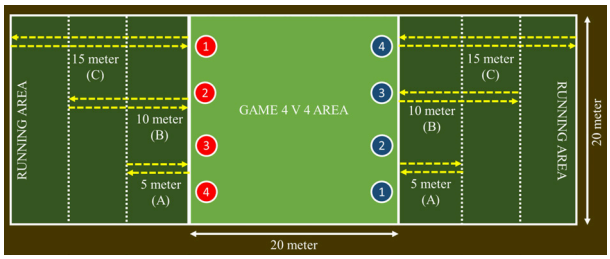

Fig. 1. ASnT method

forth of around 4-5 seconds, and a 15-meter back-and-forth of around 6-7 seconds. Thus, the total time for a 60-meter sprint is around 15 seconds.

To start the exercise, players sprint back and forth with a total distance of 60 meters. After the sprint, players will immediately play SSG for 1 minute, focusing on ball control. After completing the sprint and SSG session, players rest for the same duration as the total sprint and SSG time, which is around 1 minute 15 seconds (1 minute SSG + 15 seconds sprint), so the training and rest interval is 1:1. This session is repeated 10 times so that in one training session, the total training time (including sprint, SSG, and recovery) is around 25 minutes. This training aims to improve anaerobic endurance, with an average heart rate target of >80 % of HR Max during sprints and SSG in the high-intensity zone. The total sprints performed by each player in 1 training session are 600 meters, designed to encourage players to reach maximum speed and improve their recovery ability between intense activities.

Results

Table 1. Expert Judgement (EJ) Questionnaire Results

No	Question items	EJ1	EJ2	EJ3
1	To what extent does the training design in the product provide enough variety to maintain user interest and motivation?	4	4	3
2	Does the training design integrate aerobic and anaerobic aspects in a balanced way?	4	5	5
3	Does the training design integrate technical aspects of soccer in a balanced way?	5	4	5
4	Is there a clear progression in training design from beginner to advanced level?	5	5	4
5	Does the product provide clear and easy-to-understand instructions for users?	5	5	4
6	Will the product have an impact on users' aerobic ability?	5	4	4
7	Will the product have an impact on users' anaerobic ability?	5	5	4
8	Will the product impact users' technical ability to play soccer?	4	4	5
9	Will the product have a positive effect on users' mood?	4	3	5
10	Does the product have clear guidance and warnings regarding safe training practices and injury prevention?	5	5	4
	Total	46	44	43

Table 1 above shows the questionnaire results filled out by three expert judgments. Before the percentage analysis, the questionnaire data entered the content validity test stage. The content validation test using Aiken' V can be seen in the table below:

Table 2. Aiken' V Test Results

No	Question Items	Results EJ3	Description
1	Item 1	0.666666667	Medium
2	Item 2	0.916666667	High
3	Item 3	0.916666667	High
4	Item 4	0.916666667	High
5	Item 5	0.916666667	High
6	Item 6	0.833333333	High
7	Item 7	0.916666667	High
8	Item 8	0.833333333	High
9	Item 9	0.75	High
10	Item 10	0.916666667	Medium
Mean		0.858333333	High

Table 2 shows the evaluation results of 10 questions by three assessors, with average scores ranging from 0 to 1 and categorized into "Medium" or "High." Overall, the average score of all items is 0.86, which falls into the "High" category, indicating that the assessors rated the majority of questions very well. The next stage is a percentage test based on the results of the expert judgment assessment. This analysis aims to test the feasibility of the product being developed.

Table 3. Product Feasibility Percentage Test

No	EJ1	EJ2	EJ3	Total	Percentage	Description
1	46	44	43	133	0.886666667	Feasible

Based on Table 3, the total score from the three assessors is 133, with a feasibility percentage of 88.67%, which is categorized as "Feasible." The next stage is implementation or trial. This stage uses an experimental method for four weeks of treatment.

Table 4. Heart Rate Monitoring

Variable	Week 1	Week 2	Week 3	Week 4
Average HR	82.92 ± 2.64	83.58 ± 3.48	85.00 ± 4.41	84.92 ± 4.80
Maximum HR	95.50 ± 4.48	95.83 ± 4.37	95.17 ± 5.06	95.25 ± 5.08

Data are presented as mean ± SD

Table 4 shows that the heart rate data showed some changes during the four weeks of training. The average heart rate increased from 82.92 % HrMax in the first week to 85.00 % HrMax in the third week before decreasing slightly to 84.92 % HrMax in the fourth week. Meanwhile, the maximum heart rate remained stable, with an average value of around 95 % HrMax.

Table 5 shows the results of lactate monitoring from 20 samples over four weeks. The mean lactate increased from a baseline of 1.59 mmol/L to a peak in the third week

Table 5. Lactate Monitoring

Statistic	Baseline	Week 1	Week 2	Week 3	Week 4
Mean	1.59	6.91	6.47	7.56	4.08
Standard Deviasi	0.51	3.54	2.50	3.59	1.74

of 7.56 mmol/L before decreasing to 4.08 mmol/L in the fourth week. This pattern indicates a significant increase in lactate during the training period, followed by a decrease towards the end of the training period, which could indicate the body's adaptation to intense training.

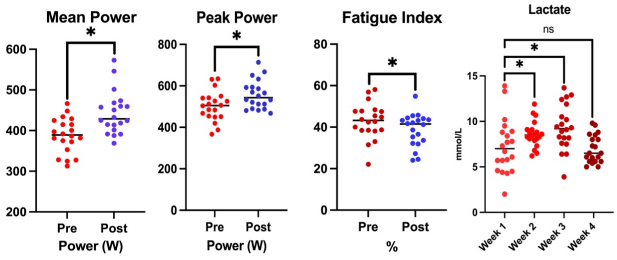

Fig. 2. Anaerobic and Physiological Performance Data Description

Figure 2 above presents the peak power (watt), mean power (watt), and fatigue index (FI) values before and after the anaerobic exercise program for 20 samples. The average peak power before exercise was 502.10 W and increased to 557.21 W after exercise, with standard deviations of 72.08 and 68.82, respectively. Mean power showed an average before exercise of 388.28 W and increased to 443.01 W after exercise, with standard deviations of 43.11 and 52.33.

Table 6. Normality Test of Anaerobic and Physiological Performance

Variable	Shapiro-Wilk		
	Statistic	Df	Sig.
Peak Power	.964	20	.622
Mean Power	.965	20	.645
Fatigue Index	.942	20	.267
Lactate Week 1 (LW1)	.952	20	.398
Lactate Week 2 (LW2)	.953	20	.422
Lactate Week 3 (LW3)	.971	20	.783
Lactate Week 4 (LW4)	.922	20	.102

The fatigue index showed an average before exercise of 42.97 and after exercise 38.68, with standard deviations of 8.58 and 7.91, respectively. These results indicate that the anaerobic exercise program has succeeded in increasing peak power and mean power and significantly reducing the fatigue index in the samples observed.

The normality test conducted using the Shapiro-Wilk test showed that all variables in the study were normally distributed with a significance value of Sig. > 0.05. Furthermore, the test continued to the hypothesis testing stage.

Table 7 shows the differences between the AnST pretest and posttest. The variables peak power, mean power, fatigue index, LW1-2, and LW1-3 showed significant differences with significance values below 0.05. While LW1-4 did not show significant differences

Discussion

This study shows that AnST has a significant impact on improving the anaerobic performance of soccer players. AnST is a combination of SET training and a soccer game approach. In training, players perform repeated sprints at high speed and then play 4 vs 4 in a 20-meter x 20-meter area interspersed with active recovery with a 1:1 interval ratio. Regarding energy use, the AnST approach applies a combination of anaerobic energy systems (ATP-PCr and glycolytic) and oxidative. When doing repeated Sprints with a total distance of 60 meters using the anaerobic system, then shifting to a 4 vs. 4 game, the energy systems contributing are anaerobic and aerobic and end with a short recovery involving the oxidative system. The AnST program includes 10 repetitions of 60-meter sprints, categorized as long-distance sprint training. Rey et al. (2024) concluded that short-distance sprint training (SST) and long-distance sprint training (LST) are both effective in improving specific soccer performance, but LST provides a more significant increase; this supports the findings of AnST, which also includes the LST category. Therefore, the AnST program can be considered an optimal approach to improve the physical capacity of soccer players.

Previous studies have shown that repeated sprint training with active recovery has been shown to improve anaerobic capacity when compared to endurance training (Sökmen et al., 2018); this further strengthens the position of AnST as an effective training tool for improving anaerobic capacity. AnST training involves a combination of repeated high-intensity sprints and short rest breaks, which aim to develop muscle

Table 7. Paired Sample T-Test Anaerobic and Physiological

Variable	Paired Differences				df	Sig. (2-tailed)
	Mean	Std. Deviation	95 % Confidence Interval of the Difference			
			Lower	Upper		
Peak Power	-55.11	63.17	-84.68	-25.54	19	.001*
Mean Power	-54.74	43.07	-74.90	-34.58	19	.000*
Fatigue Index	4.29	6.97	1.03	7.55	19	.013*
LW1-LW2	-1.35	2.36	-2.44	-2.53	19	.020*
LW1-LW3	-2.08	4.16	-4.03	-.13	19	.030*
LW1-LW4	.32	2.93	-1.05	1.69	19	.631

Data are presented as mean ± SD; (*): Significant at pretest ($p < 0.05$)

endurance and anaerobic capacity (Garciá-Pinillos et al., 2017; Rosenblat et al., 2020). This training method is essential for soccer players because they often have to sprint during matches, followed by a short recovery phase before the next sprint. With AnST training, players can be more effective in maintaining speed performance, increasing physical endurance, and reducing the risk of fatigue in the final phase of the match.

Significant results related to physiological responses, especially heart rate (HR), were obtained during the four-week AnST program. Throughout the time, the training zone consistently reached high intensity in each session. This finding is in line with previous studies examining the combination of SSG and running training, which recorded HR of 88.9 ± 2.5 % of HRmax in a 3-sided model and 86.8 ± 4.0 % of HRmax in a 4-sided model (Köklü et al., 2020). Previous studies have also found comparable results, showing that HR remains in the high-intensity category (Brandes & Elvers, 2017; Halouani et al., 2017). Previous findings also suggest that high-intensity interval training can improve aerobic and anaerobic performance in soccer players (Arazi et al., 2017; Fang et al., 2021). AnST training has been shown to consistently produce high levels of cardiovascular activity, with participants' HR always in the intense zone. This condition can be interpreted as a physiological response due to the high training intensity. In addition to HR, interestingly, this study also highlights the lactate levels that arise due to high-intensity training. In the first three weeks of AnST, lactate levels were significantly increased after the training session. The increased lactate concentration is believed to originate from the glycolytic flow rate (Piero et al., 2018). High-intensity interval training induces more significant glycolytic activity, with a short time resulting in high lactic acid, and this activity beneficially contributes to producing higher levels of ATP (Stöggl & Björklund, 2017). To reduce high lactate, the role of short recovery in AnST is crucial during repeated sprint sessions and 4 vs 4 games. During short rest periods, the oxidative system plays a role in oxidizing lactate, removing accumulated inorganic phosphate (Pi), and re-synthesizing phosphocreatine (PCr) (Turner & Stewart, 2013). These results are in line with previous studies examining the combined response of SSG with running training, which resulted in LA – 9.6 ± 1.9 mmol·L^{-1} in a 3-sided model and 8.2 ± 1.79 mmol·L^{-1} in a 4-sided model (Köklü et al., 2020). Previous studies also obtained similar results, namely high lactate levels (Chmura et al., 2023).

Conclusions

Overall, the development of an anaerobic soccer training model can improve anaerobic ability, and this training is proven to be by the physiological demands of anaerobic training, namely training that produces a high heart rate and high lactate tolerance.

Conflict of interest

No conflict of interest was reported by the authors.

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Модель анаеробного тренування у футболі: Підвищення результативності футболістів шляхом поєднання методу повторних спринтерських забігів та ігор за схемою 4 на 4

І Дева Маде Арянанда Віджая Кусума[1ABCD], Нінін Відьях Куснанік[1ACD], Баю Агун Прамоно[1ACD], Аді Праното[1ACD], Яньон Пханпхен[2ACD], Індра Хімаван Сусанто[1BCD], Дева Аю Праба Амустікарані[1BCD], Варістра Тьо Нірваншах[1BCD], Мухаммад Багус Фірзам Бхарламан[1BCD]

[1]Сурабайський державний університет
[2]Лоейський університет Раджабхат

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

Реферат. Стаття: 8 с., 7 табл., 2 рис., 34 джерела.

Мета дослідження. Модель анаеробного тренування у футболі (Anaerobic Soccer Training, AnST) була розроблена для підвищення варіативності тренувальних програм за рахунок впровадження ігрового підходу до відповідності характеристик. Це дослідження мало на меті оцінити ефективність тренувальної моделі з точки зору покращення показників анаеробних здібностей футболістів.

Матеріали та методи. В якості методу дослідження застосовано модель ADDIE (Analysis, Design, Development, Implementation, and Evaluation), що включає п'ять інтегрованих етапів: аналіз, дизайн, розробка, впровадження та оцінка. У дослідженні взяли участь 82 футболісти з чоловічого студентського осередку університету UNESA, 20 з яких були відібрані за методом рандомізації. Характеристики вибірки включали такі показники: вік 20,05 ± 0,69 років, зріст 165,85 ± 5,00 см, вага 62,08 ± 6,82 кг, IMT 22,54 ± 1,98. Інтервенція проводилась впродовж чотиритижневого періоду, з частотою тричі на тиждень. З метою аналізу даних оцінок, отриманих від трьох експертних висновків, використовувався V-критерій Ейкена, з подальшим відсотковим аналізом для перевірки валідності змісту. Перевірка нормальності розподілу проводилась з використанням критерію Шапіро-Уілка, а середня різниця була проаналізована за допомогою t-критерію для парних вибірок.

Результати. За результатами дослідження встановлено, що у змінних максимальної потужності (.001), середньої потужності (.000), індексу втоми (.013), показників рівня лактату впродовж тижня (LW) 1-2 (.020) та LW1-3 (.038) спостерігалися суттєві відмінності зі значеннями рівня значущості нижче 0.05. Натомість, показник LW1-4 (.631) не продемонстрував достовірних відмінностей. Загалом, розробка моделі анаеробного тренування у футболі сприяла покращенню анаеробних здібностей гравців, про що свідчить підвищення показників максимальної потужності, середньої потужності та зниження рівня індексу втоми.

Висновки. Отримані дані вказують на ефективність застосування зазначеної моделі тренувань в контексті поліпшення показників анаеробної продуктивності футболістів.

Ключові слова: анаеробний, тренування з футболу, повторний спринт, ігри неповними складами команд.

Information about the authors:

Kusuma, I Dewa Made Aryananda Wijaya: dewawijaya@unesa.ac.id; https://orcid.org/0000-0002-4939-7294; Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Kusnanik, Nining Widyah: niningwidyah@unesa.ac.id; https://orcid.org/0000-0002-0734-6843; Department of Sport Coaching Education, Faculty of Sport Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Pramono, Bayu Agung: bayupramono@unesa.ac.id; https://orcid.org/0000-0002-9308-1289; Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Pranoto, Adi: adipranoto@unesa.ac.id; https://orcid.org/0000-0003-4080-9245; Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Phanpheng, Yanyong: yanyong.pha@lru.ac.th; https://orcid.org/0000-0002-9290-2479; Sports and Exercise Science Program, Faculty of Science and Technology, Loei Rajabhat University, 234 Loei - Chiang Khan Road, Loei 42000, Thailand.

Susanto, Indra Himawan: indrasusanto@unesa.ac.id; https://orcid.org/0000-0001-6132-9051; Department of Sport Science, Faculty of Sports and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Amustikarani, Dewa Ayu Praba: dewarani@unesa.ac.id; https://orcid.org/0009-0001-5513-5821; Faculty of Medicine, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Nirwansyah, Waristra Tyo: waristra.21043@mhs.unesa.ac.id; https://orcid.org/0009-0005-2314-9064; Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Bharlaman, Muhammad Bagus Firzam: bagusfirzam18@gmail.com; https://orcid.org/0009-0001-8703-3889; Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

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Original Scientific Article

Evaluating the Effects of Three High Intensity Interval Training Protocols on Maximum Oxygen Consumption and Leg Strength in Recreational Football Athletes

Wirat Sonchan[1ABCE], Saralee Sonchan[1CD] and Ratanyoo Longrak[1BDE]

[1]Burapha University

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

Corresponding Author: Wirat Sonchan, e-mail: wirats@go.buu.ac.th
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Abstract

Objectives. This study aimed to examine the effects of three high intensity interval training (HIIT) protocols on VO_2max and leg strength in recreational football athletes.

Materials and methods. Thirty-one participants were recruited and randomly assigned to one of three HIIT protocols: HIIT20/20, HIIT40/10, or HIIT60/5. The training programs spanned 6 weeks with a frequency of 3 sessions per week on non-consecutive days. Baseline testing for VO_2max and leg strength was conducted using an incremental exercise test with blood gas analysis and an isokinetic machine, respectively, at 1 week before the intervention, and post-intervention testing occurred 1 week after the last training session. A two-way repeated measures ANOVA was employed to compare changes between groups and across time points.

Results. The results demonstrated that there was a significant increase in VO_2max in both the HIIT40/10 (Δ 10.4 %, CI 95 % = 1.67-7.42 ml/kg/min, ES = Moderate) and HIIT60/5 (Δ 12 %, CI 95 % = 2.28-8.84, ES = Moderate) groups, while no considerable changes were observed in leg strength across any group ($p > 0.05$). Additionally, a Weak but substantial correlation between leg strength and VO_2max was found at both pre-intervention ($r = 0.39$) and post-intervention ($r = 0.38$) periods.

Conclusions. In conclusion, if the training goal was to improve VO_2max through HIIT, both the HIIT40/10 and HIIT60/5 protocols were more effective than HIIT20/20.

Keywords: maximum oxygen consumption, VO_2max, sprint training, leg strength, football.

Introduction

Football (or Soccer) is a high-intensity, intermittent sport that requires athletes to sustain performance over a 90-minute game (Stølen et al., 2005). Players are constantly engaged in activities like sprinting, jogging, and walking, with frequent changes in direction and pace (Bradley et al., 2015). The physical demands of football necessitate excellent cardiovascular endurance and muscular strength, as athletes must maintain a high level of effort throughout the match. Previous study reported that the professional football players covered the total distances about 9 to 14 km per match (Sarmento et al., 2014). Without sufficient fitness, players might experience fatigue, which can affect their ability to make quick decisions and execute skilled movements effectively, especially during the latter stages of the game (Smith et al., 2016).

The maximum oxygen consumption (VO_2max) during exercise, is widely recognized as a key indicator of cardiovascular fitness (Modric et al., 2020). In football, VO_2max reflects an athlete's ability to perform sustained aerobic work, which is crucial for maintaining high levels of activity throughout the game. The previous study demonstrated that VO_2max values were in the range of 48 to 62 ml/kg/min for male soccer players; especially in professional players, the values were about 57.8 to 61.7 ml/kg/min (Slimani et al., 2019). Athletes with higher VO_2max can recover more efficiently between high-intensity bouts, allowing them to maintain performance during crucial moments (Tomlin et al., 2001). Improving VO_2max through targeted training can enhance an athlete's overall endurance (Scribbans et al., 2016).

ТМФВ
ТОВ ОВС

High-Intensity Interval Training (HIIT) has garnered significant interest as one of the most effective methods for improving VO_2max (Atakan et al., 2021). By alternating between short bursts of intense exercise and recovery periods, HIIT places a greater demand on the cardiovascular and respiratory systems than traditional endurance training (Gibala et al., 2012). Studies have shown that various protocols of HIIT can lead to significant improvements in VO_2max (Helgerud et al., 2007; Fernandez-Fernandez et al., 2012; Monks et al., 2017), regardless of differences in the specific protocol.

In addition to cardiovascular endurance, leg strength plays a pivotal role in football performance (Stølen et al., 2005). The ability to generate force in the legs is critical for key actions such as sprinting, jumping, kicking, and clearing long passes (Cometti et al., 2001). Interestingly, HIIT has been shown to elicit multifaceted adaptations, not only improving VO_2max but also enhancing maximum leg strength (Caparrós-Manosalva et al., 2023). This increased leg strength contributes to better speed and power while helping athletes sustain high levels of intensity during physically demanding matches.

Given the importance of both aerobic capacity and leg strength in football, the present study aimed to investigate the effects of three HIIT protocols on VO_2max and leg strength in recreational football athletes.

Materials and Methods

Study Participants

Thirty-one healthy, physically active young men were recruited for this study. The sample size was determined using G*Power software version 3.1.9.7, with a priori power analysis indicating an effect size of 0.8, an alpha level of 0.05, and a power (1-ß) of 0.95. Eligibility criteria included: 1) healthy male undergraduate students aged 18-24, 2) at least 1 years of recreational football experience, and 3) no pre-existing medical conditions (e.g., hypertension, cardiac disease, diabetes) that could impede participation. A certified hospital physician conducted a comprehensive health assessment to confirm eligibility. Participants were randomly assigned to one of three groups: HIIT20/20 (n = 10), HIIT40/10 (n = 10), or HIIT60/5 (n = 11) using the Research Randomizer website (www.randomlists.com).

All participants provided informed consent prior to their involvement, and the study adhered to the Declaration of Helsinki. Moreover, approval for the study protocol was obtained from the Institutional Review Board of Burapha University (No. IRB1-015/2565).

Experimental Design

The study investigated the effects of high intensity interval training (HIIT) protocols on VO_2max and leg strength in recreational football athletes. Participants were randomly divided into three groups: HIIT20/20, HIIT40/10, and HIIT60/5. The protocols were applied over 6 weeks using a single-blind design. Eligibility was restricted to recreational footballers who played less than three times per week to ensure they were non-professional and played primarily for leisure. VO_2max and leg strength were assessed one week before and one week after the training intervention, under controlled conditions.

High Intensity Interval Training

All training groups participated in a 6-week program, engaging in their assigned HIIT protocols three times per week. Each session commenced at the Burapha University football field, where participants were supervised closely throughout session. The session began with a 5-minute warm-up involving dynamic stretching and light jogging to prepare the participants. The HIIT consisted of "all-out" repeated sprints performed at maximum effort of that current state. For the HIIT20/20 protocol, participants completed 20 sets of "all-out" repeated sprinting over a distance of 20 meters, with a 30-second rest interval between bouts. For the HIIT40/10 protocol, participants performed 10 sets of "all-out" repeated sprinting over 40 meters, with a 30-second rest interval between bouts. Last but not least, for the HIIT60/5 protocol, participants performed 5 sets of "all-out" repeated sprinting over 60 meters, with a 30-second rest interval between bouts. After completing the training session, all groups concluded with a 5-minute cool-down period, which included light jogging and static stretching of the total body. Throughout these 6-week training programs, participants were instructed to refrain from engaging in any additional training activities of all kind.

Leg Strength Assessment

The assessment of muscle strength of dominant leg was conducted by the isokinetic machine (ISOFORCE, Germany), recognized as the gold-standard for evaluating muscular strength (Chamorro et al., 2017). Pre-intervention testing occurred one week prior to the commencement of the training program as well as all post-intervention was on 1 week after last training session. The testing began with a 5-minute warm-up comprising light treadmill walking and dynamic stretching exercises targeting the knee extensor groups. Participants were seated and securely fastened with strap belts to ensure stable positioning of the torso and upper thighs (about 90 degrees of hip flexion). Clear instructions were read out loud to participants that "you have to kick up your legs as hard and fast as possible, with maximal effort against the ankle pad, which was programed to move at the angular velocity of 60 degrees per second, starting from a knee flexion of 90 degrees to full knee extension". Each participant performed three maximum effort attempts, with a 120-second rest interval between attempts.

Maximum Oxygen Consumption Assessment

The assessment of VO_2max was conducted following the modified Bruce Protocol. This protocol was utilized in previous study for evaluating cardiorespiratory fitness from the treadmill incremental exercise test (Ham et al., 2017). Participants were instructed to wear a specialized mask (Hans Rudolph, Kansas, USA) designed to cover both the nose and mouth with very little dead spaces, enabling the collection of respiratory gases, facilitated by a respiratory gas analyzer (Oxycon Mobile, Germany). Participants were instructed to maintain natural breathing patterns through

the mask during the assessment. The protocol commenced with participants instructed to run on the treadmill (T7-0, Life Fitness, Illinois, USA) at starting speed of 3.6 km/h for an initial duration of 2 minutes. Subsequently, the speed of treadmill constantly increased at 1.2 km/h for every 2 minutes. This modified protocol constantly kept the grade to 0 % (Table 1). This incremental exercise test ensured a progressive increase in cardiovascular demand with increased speed, pushing participants towards their maximal aerobic capacity. The test was terminated when participants reached volitional exhaustion, indicated by an inability to maintain the required speed on the treadmill. The heart rate was continuously measured during the test by means of a heart rate monitor (H10, Polar, Finland).

Table 1. The modified Bruce Protocol

Speed (km/h)	Time (min)
3.6	0-2
4.8	2-4
6.0	4-6
7.2	6-8
8.4	8-10
9.6	10-12
10.8	12-14
12.0	14-20
13.2	20-22
14.4	22-24
15.6	24-26

Grade (%) remained at 0 throughout the testing period

Statistical Analysis

The statistical analysis was calculated to investigate the effects of three different HIIT protocols on leg muscle strength, short-distance sprint performance, and maximum oxygen uptake in football athletes. The Shapiro-Wilk test was analyzed for the distribution of data. Descriptive statistics were used to summarize participants' baseline characteristics. Baseline variables between groups was compared by One-way ANOVA. Levene's test was used to assess the homogeneity of variances. Changes in VO_2max and leg strength from Pre to Post were calculated and a two-way repeated measured ANOVA was employed to compare the effects between groups (HIIT20/20 vs HIIT40/10 vs HIIT60/5) and times (Pre vs. Post). Cohen's d effect size was calculated using the following formula: mean change/pooled SD, with being interpreted according to the Hopkins' recommendations: 0.00-0.19: Trivial; 0.20-0.59: Small: 0.60-1.19: Moderate; 1.20–1.99: Large; ≥2.00: Very large (Hopkins et al., 2009). Moreover, the Pearson's correlation coefficient was also calculated to examine the relationships between VO_2max and leg strength at both pre and post-test, with the interpretation of values according to the previous study: 0.00-0.09 – Negligible; 0.10-0.39 – Weak; 0.40-0.69 – Moderate; 0.70-0.89 – Strong; 0.90-1.00 – Very strong (Schober et al., 2018). Statistical analyses were performed using IBM SPSS Statistics version 20, with a significance level set at $\alpha = 0.05$.

Results

At the beginning of the test, the statistical analysis indicated no significant differences in participants' baseline characteristics ($p > 0.05$) (Table 2). Furthermore, all participants completed the training program with 100 % adherence.

A significant time effect was observed VO_2max ($F_{(1,28)} = 24.441$, $p = 0.000$, $\eta_2^p = 0.466$), indicating changes over time in these variables, while no time effect was observed for leg strength. Additionally, no significant main group or interaction effects were detected ($p > 0.05$) (Table 3).

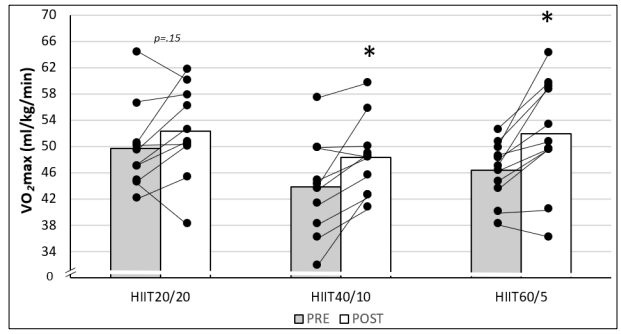

Fig. 1. Maximum oxygen consumption values from pre- to post-intervention with individual analyses. * indicated significantly different from pre-intervention ($p < 0.01$)

Specifically, only HIIT40/10 and HIIT60/5 showed significant increases in VO_2max from baseline (Δ10.38 %, d = 0.68, p = 0.006; Δ11.98 %, d = 0.83, p = 0.004, respectively) (Figure 1). Conversely, no groups demonstrated a significant increase in leg strength after 6-week HIIT.

Table 2. Baselines of participants' characteristics and performance

Variable	HIIT20/20 (n=10) mean ± SD	HIIT40/10 (n=10) mean ± SD	HIIT60/5 (n=11) mean ± SD	F	p
Age (years)	20.30 ± 0.82	20.20 ± 1.14	20.55 ± 1.04	0.33	0.72
Height (cm)	176.70 ± 5.74	176.40 ± 1.14	172.36 ± 7.97	1.53	0.23
Body mass (kg)	64.90 ± 9.09	68.80 ± 8.78	69.45 ± 12.23	0.59	0.56
Leg strength (Nm/kg)	2.84 ± 0.60	2.85 ± 0.45	2.79 ± 0.65	0.09	0.97
VO_2max (ml/kg/min)	49.72 ± 6.53	43.82 ± 7.41	46.42 ± 4.40	2.29	0.12

Data were presented as mean ± standard deviation. Abbreviation: VO_2max

Table 3. Change from Pre to Post

Measurement	HIIT20/20 (n = 10)			HIIT40/10 (n = 10)			HIIT60/5 (n = 11)			Effect p		
	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95 % CI)	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95 % CI)	Pre (mean ± S.D.)	Post (mean ± S.D.)	Δ (95 % CI)	Group	Time	Interaction
VO_2max (ml/kg/min)	49.72 ± 6.53	52.36 ± 7.08	2.63 (-1.18; 6.44)	43.82 ± 7.41	48.37 ± 5.95*	4.55 (1.67; 7.42)	46.42 ± 4.40	51.98 ± 8.42*	5.56 (2.28; 8.84)	0.226	0.000	0.380
Leg strength (Nm/kg)	2.84 ± 0.60	2.93 ± 0.60	0.09 (-.05; .22)	2.85 ± 0.45	2.72 ± 0.69	-0.13 (-.43; 0.17)	2.79 ± 0.65	2.79 ± 0.56	-0.00 (-0.20; .19)	0.902	0.797	0.309

Data were presented as mean ± standard deviation. Abbreviation: VO_2max = Maximal oxygen uptake; ES = Effect size; 95 % CI = 95 % Confidence Interval. * p < 0.01 compared to Pre.

Moreover, the Pearson's correlation coefficient indicated Weak but significant correlations between VO_2max and leg strength at both pre-intervention (r = 0.39) and post-intervention (r = 0.38) (Figure 2).

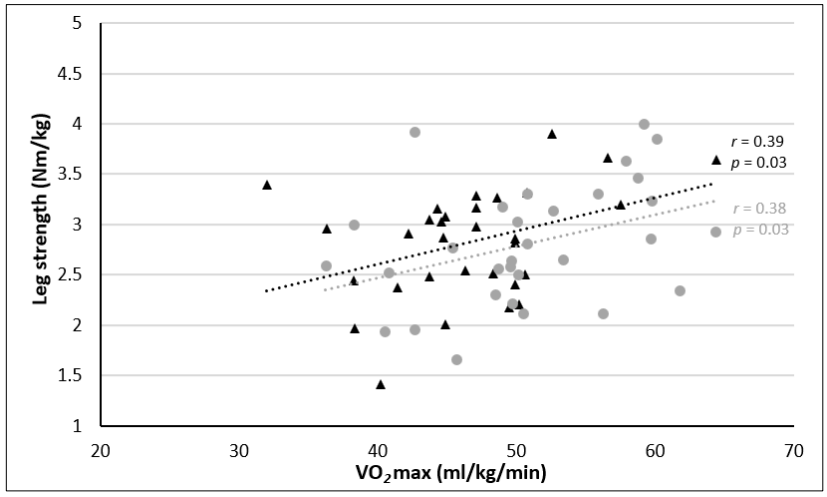

Fig. 2. Correlations between maximum oxygen consumption (VO_2max) and leg strength at pre-intervention (Black triangle) and post-intervention (Light grey circle)

Discussion

This study was the first to demonstrate that not all HIIT protocols are equally effective in increasing VO_2max. We found that the HIIT20/20 protocol was less effective than HIIT40/10 or HIIT60/5 in producing significant improvements in aerobic fitness. However, none of the HIIT protocols in this study led to a significant increase in leg strength after six weeks of training.

The main findings of our study are consistent with previous research demonstrating that short-term HIIT can increase VO_2max to a certain extent. For example, Milioni et al. (2024) reported that just four weeks of 10 bouts of 1-minute sprints at 90 % of maximum velocity significantly increased VO_2max by approximately 2.1 ml/kg/min from baseline. Similarly, Raleigh et al. (2018) found that eight 20-second bouts of maximum cycling increased VO_2max by up to 4.7 ml/kg/min after just four weeks of training. Likewise, Kim et al. (2011) demonstrated that ten 30-second maximum sprint bouts resulted in a significant VO_2max increase of 3.92 ml/kg/min after eight weeks of training.

Theoretically, the increase in maximum oxygen consumption can theoretically be attributed to improvements in two key areas: 1) central adaptations, which involve an enlargement of left ventricular volume, enhanced contractility, and increased blood volume, all contributing to a greater stroke volume (Hellsten & Nyberg, 2015); and 2) peripheral adaptations, which enhance the muscles' ability to extract oxygen and generate ATP aerobically (Daussin et al., 2007). It is likely that high-intensity interval training can improve both mechanisms within a relatively short time frame.

To support this, previous studies have demonstrated that HIIT can induce various peripheral adaptations, such as increases in mitochondrial numbers (Torma et al., 2019) and oxidative enzymes (Gillen et al., 2014) after a short period of training. Additionally, HIIT has been shown to stimulate the expression of vascular growth factors, like vascular endothelial growth factor (VEGF), which promotes new blood vessel formation (MacInnis & Gibala, 2016). From a physiological standpoint, it is likely that the HIIT40/10 and HIIT60/5 protocols in our study resulted in greater adaptations in these mechanisms. Consequently, the capacity to extract oxygen from the blood and generate ATP aerobically increased significantly in these groups, as evidenced by the significant improvement in VO_2max (Raleigh et al., 2018). In contrast, the adaptations in the HIIT20/20 protocol may have been suboptimal.

One possible explanation for the results is that the distance covered in each bout of the HIIT20/20 protocol was too short, as participants only sprinted about 20 meters, which took approximately 3 to 3.5 seconds. This short-duration effort may not have been sufficiently taxing to induce the internal stress required, as compared to the

40-meter or 60-meter sprints. The molecular response to interval stress and ATP deficit, such as activation of the AMP-activated protein kinase (AMPK) signaling pathway, might not have been adequately triggered by the shorter sprints (Winder et al., 2006). This signaling pathway is known to enhance several aspects of aerobic capacity, including improved fat oxidation, increased mitochondrial biogenesis, stimulated capillarization, and fiber type transformation (Spaulding & Yan, 2022), all of which are well-established contributors to improved aerobic performance. Therefore, practitioners of HIIT should consider bout duration or distance as critical training factors. However, our study did not examine cellular or molecular responses in detail. Future research should explore our hypothesis regarding these adaptations.

Moreover, we found that the leg strength of our participants did not significantly change after six weeks of HIIT, regardless of the protocol used. It is likely that the participants were not untrained or weak subjects who could benefit from low external load activities, as they only sprinted using their body weight. Therefore, to adhere to the principles of training necessary for inducing physiological adaptations in muscle strength, external moderate to heavy load modalities should be employed (ACSM, 2009).

For instance, high-intensity interval training (HIIT) can be performed on loaded stationary bikes or with weight vests. Additionally, to align with the principle of specificity (Kasper, 2019) for football athletes aiming to increase lower-body strength, it is essential to incorporate resistance training exercises such as the leg press or back squat (Wirth et al., 2016) as the primary modalities for enhancing leg strength. In this study, a Weak but significant correlation was found between leg strength and VO_2max at both pre- ($r = 0.39$, $p = 0.03$) and post-intervention ($r = 0.38$, $p = 0.03$), indicating that improvements in leg strength might positively benefit VO_2max in football athletes. This finding further underscores the necessity of leg strength training in enhancing overall athletic performance.

Conclusions

In summary, our study clearly showed that not all HIIT protocols are created equal for improving VO_2max. We recommend the HIIT40/10 and HIIT60/5 protocols, as they demonstrated superior results compared to HIIT 20/20. Furthermore, training with HIIT alone, regardless of the protocol used, is unlikely to produce significant increases in leg strength within a short time frame.

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Conflict of interest

The authors guarantee that no conflicts of interest exist.

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Оцінка впливу застосування трьох протоколів високоінтенсивного інтервального тренування на показники максимального споживання кисню та сили ніг у спортсменів з рекреаційного футболу

Вірат Сончан[1ABCDE], Саралі Сончан[1CD], Ратаню Лонграк[1BDE]

[1]Бурафа університет

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

Реферат. Стаття: 7 с., 3 табл., 2 рис., 31 джерело.

Мета дослідження. Мета дослідження полягала у вивченні впливу застосування трьох протоколів високоінтенсивного інтервального тренування (ВІІТ) на показники VO_2max та сили ніг у спортсменів з рекреаційного футболу.

Матеріали та методи. До участі в дослідженні було залучено 31 учасника, яких розподілили за методом рандомізації з метою виконання фізичних вправ одного з трьох протоколів ВІІТ: ВІІТ20/20, ВІІТ40/10 або ВІІТ60/5. Тренувальні програми тривали 6 тижнів з частотою 3 заняття на тиждень у різні дні. Початкове вимірювання показників VO_2max та сили ніг проводилось за допомогою інкрементного тесту на визначення рівня фізичної підготовленості з використанням аналізу для оцінки рівня кисню та вуглекислого газу в крові та ізокінетичного апарату, відповідно, на етапі за 1 тиждень до проведення інтервенції, а постінтервенційне тестування — через 1 тиждень після останньої тренувальної сесії. З метою порівняльного аналізу змін між групами та часовими точками було застосовано двофакторний дисперсійний аналіз із повторними вимірами (ANOVA).

Результати. За результатами дослідження встановлено значне підвищення рівня VO_2max у групах ВІІТ40/10 (Δ 10,4 %, довірчий інтервал, CI 95 % = 1,67-7,42 мл/кг/хв, розмір ефекту, ES = Помірний) та ВІІТ60/5 (Δ 12 %, CI 95 % = 2,28-8,84, ES = Помірний), тоді як істотних змін у показниках сили ніг у жодній з груп не спостерігалося ($p > 0,05$). Крім того, було виявлено слабкий, але суттєвий кореляційний зв'язок між показниками сили ніг та VO_2max як на передінтервенційному ($r = 0,39$), так і на постінтервенційному періодах дослідження ($r = 0,38$).

Висновки. Отже, якщо метою тренування було покращення показників VO_2max за допомогою програми ВІІТ, застосування обох протоколів ВІІТ40/10 і ВІІТ60/5 показало більшу ефективність, ніж ВІІТ20/20.

Ключові слова: максимальне споживання кисню, VO_2max, спринтерське тренування, сила ніг, футбол.

Information about the authors:

Sonchan, Wirat: wirats@go.buu.ac.th; https://orcid.org/0000-0001-9985-7765; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

Sonchan, Saralee: saralee@go.buu.ac.th; https://orcid.org/0000-0002-7545-4328; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

Longrak, Ratanyoo: addmuscleclinicz@gmail.com; https://orcid.org/0000-0001-6117-7617; Faculty of Sport Science, Burapha University, 169 Long Had Bangsaen Rd, Saen Suk, Chon Buri 20131, Thailand.

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Original Scientific Article

Applying a 12-Week TRX Suspension and Plyometric Training Program: Effects on Biomotor Abilities and Physiological Adaptations in Volleyball Players

Abhijith Muriyedath[1ABCDE], Masilamani Elayaraja[1ABCDE], Nirmal Michael Salvi[2ABCDE], Farjana Akter Boby[3ACD], Bekir Erhan Orhan[4ACDE], Yuni Astuti[5ACDE] and Karuppasamy Govindasamy[2ACDE]

[1]Pondicherry University
[2]Symbiosis International (Deemed University)
[3]Daffodil International University
[4]Istanbul Aydin University
[5]Universitas Negeri Padang

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

Corresponding Author: Yuni Astuti, e-mail: yuniastuti@fik.unp.ac.id
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Abstract

Background. Volleyball players require a combination of physical and physiological abilities to enhance performance, and TRX suspension and plyometric training are known to improve these abilities. However, evidence comparing their effectiveness in volleyball players is limited.

Objectives. This study aimed to investigate the effects of a 12-week TRX suspension and plyometric training program on biomotor abilities and physiological adaptations in male volleyball players.

Materials and methods. Forty-five male athletes (age: 21.91 ± 1.10) from Calicut University, Kerala, India, were involved in the study. The participants were divided into three groups: TRX suspension training, plyometric training, and a control group. Speed, agility, explosive power, vital capacity, and resting heart rate were measured before and after the intervention. The data were then subjected to statistical analyses, including linear mixed-effects models and repeated measures ANOVA, in order to assess group-by-time interactions.

Results. The findings indicate significant improvements in speed ($p < 0.001$), agility ($p = 0.003$), and explosive power ($p < 0.001$) in both training groups, with notable group-by-time interactions. Vital capacity also showed substantial enhancements ($p < 0.001$), while resting heart rate remained unchanged.

Conclusions. In conclusion, both TRX suspension and plyometric training have been revealed to be effective in enhancing biomotor abilities and vital capacity in volleyball players, making them viable options for improving performance, without affecting resting heart rate.

Keywords: speed, agility, explosive power, volleyball, resting heart rate.

Introduction

Volleyball is an extremely demanding sport that requires a combination of varying levels of speed, agility (change of direction), power production and endurance (Weldon et al., 2021). These physical traits are indispensable as athletes must perform quick, powerful movements such as jumps, strikes and lateral sprints, making the training of these biomotor skills essential to success (Bashir et al., 2022; Cao et al., 2024). With all the physical work required, specific training methods are essential for improving key volleyball performance fundamentals, such as block-jumping ability and overall physiological fitness (Keoliya et al., 2024). TRX Suspension and Plyometric training are widely recognized among the various existing training methods but have not yet been systematically compared in the perspective of volleyball players.

TRX Suspension training is a form of bodyweight exercise which develops strength, balance, flexibility and core stability (Gaedtke & Morat, 2015). It is a whole body method to training that uses several muscle groups at the same time. This makes it extremely advantageous for those athletes who need as much coordination or even cross enabled strength possible (Khorjahani et al., 2021a). TRX Suspension training provides improvements in core stability and functional strength, which are especially important for volleyball players that perform a variety of dynamic, multi-directional movements (Fong et al., 2015). However, this form of training has been proven to improve basic functions in volleyball, such as jumping, spiking with a spike jump and general balance mechanisms while performing defensive actions, e.g., blocking (Ozdamar et al., 2024). Several studies have highlighted that this type of training can improve components of cardiovascular fitness, strength and power, which are characteristics required for optimal performance in volleyball (Cardoso Marques et al., 2006; Niculescu, 2011; Thuc, 2018; Tinto et al., 2017). Furthermore, the instability properties of TRX exercises may enhance neuromuscular coordination and balance which are vital for the complex movement patterning required in volleyball (Nešić et al., 2020; Wang & Liang, 2021). Whilst the investigation into TRX Suspension Training effectiveness in volleyball players is scarce, available evidence provides some support for its inclusion as part of a balanced physical preparation program.

Plyometric training, on the other hand, is intended to improve explosive power and strength through rapid muscle contractions (Bastholm, 2024). Training in this way helps to utilize the stretch-shortening cycle of the muscles, which can help developing greater forces at a faster rate in athletes (Wang et al., 2023). This exercises are predominantly effective in improving athletes' vertical jump height, which is important for volleyball players who frequently jump to spike or block during games (Tupinambá Oliveira et al., 2023). Several existing research supports Plyometric training for its ability to enhance rapid force production, speed, and agility qualities which are fundamental to the quick, powerful movements required in volleyball (Booth & Orr, 2016; Chaturvedi et al., 2023; Kons et al., 2023).

While TRX suspension and plyometric training have both been extensively studied for their benefits to athletes, however most of the existing literature tends to focus on general populations or athletes from sports such as soccer, basketball, and track and field, rather than volleyball players (Aslani et al., 2018; Bastholm, 2024; Cao et al., 2024; Liu et al., 2024; Negra et al., 2017). Few studies specifically explore the impact of these training methods on volleyball players' performance, particularly in terms of key outcomes like vertical jump height, agility, and speed. Additionally, the physiological adaptations brought about by these training methods, such as changes in resting heart rate and vital capacity, have rarely been examined in volleyball players (MacInnis & Gibala, 2017; Manna et al., 2012; Périard et al., 2021).

Given the limitations in existing research, there is a need for studies that compare the effectiveness of TRX Suspension and Plyometric training on both bio motor abilities and physiological parameters in volleyball players. Therefore, this study aims to investigate the effects of a 12-week training program incorporating both methods on performance indicators such as speed, agility, and explosive power, as well as on physiological variables like resting heart rate and vital capacity, to determine which approach is more effective in enhancing volleyball performance.

Materials and Methods

This study utilized a randomized control trial with pre-test, post-test, TRXG, PTG, and CG. Every research participant was randomly divided into three groups (TRXG, PTG, or CG). Subjects were asked to continue their voluntary participation throughout the program. The study included three phases: pre-testing, training interventions, and post-testing. Furthermore, pre-and post-test procedures were carried out two days before and following the 12-week training program. All participants underwent a trial testing session prior to the pre- and post-test. Before beginning the entire study process, the research study and study procedure were approved (HEC/PU/2023/10/07-08-2023) by the Institutional Ethical Committee at Pondicherry University, India, in accordance with the Helsinki Declaration.

Study Participants

Initially, the study comprised 47 male volleyball players from various affiliated colleges in Calicut University, Kerala, India, aged between 18-24 years. All of the participants (n = 47) participated in intercollegiate tournaments. However, two volleyball players were excluded from the study due to pre-existing musculoskeletal injuries. The remaining participants (n = 45) had no history of injury. Each player had a minimum of two years of prior volleyball experience and at least six months of training experience in plyometric and traditional resistance training; they were considered as study participants. Before the commencement of the training and testing procedures, the researcher provided a detailed explanation of the research objective, both verbally and in writing, to ensure their complete understanding of the study. Informed consent was obtained from all participants in written form, including their voluntary consent to participate in the study. Once the procedure for inclusion and exclusion was completed, the characteristics of the participants who remained in the study were as follows: age = 21.91 ± 1.10, weight = 82 ± 6.35, and height = 1.84 ± 0.6. The study design and sample sizes at various stages of the research are depicted graphically in Figure 1.

Outcome Measures

In this study, the outcome measures assessed including bio motor abilities such as speed, agility, and explosive power, alongside physiological adaptation, which includes resting heart rate and vital capacity. All testing measurements were conducted both before and after (pre and post-test) the 12 weeks of the intervention period (TRX and PT). Throughout the testing process, the researcher ensured participant safety by supervision and implementing proper warming up and warming down procedures to minimize the risk of injury and optimize performance during the assessment.

Speed

The speed was evaluated by means of a 50-meter run that was adapted from the procedures described in earlier

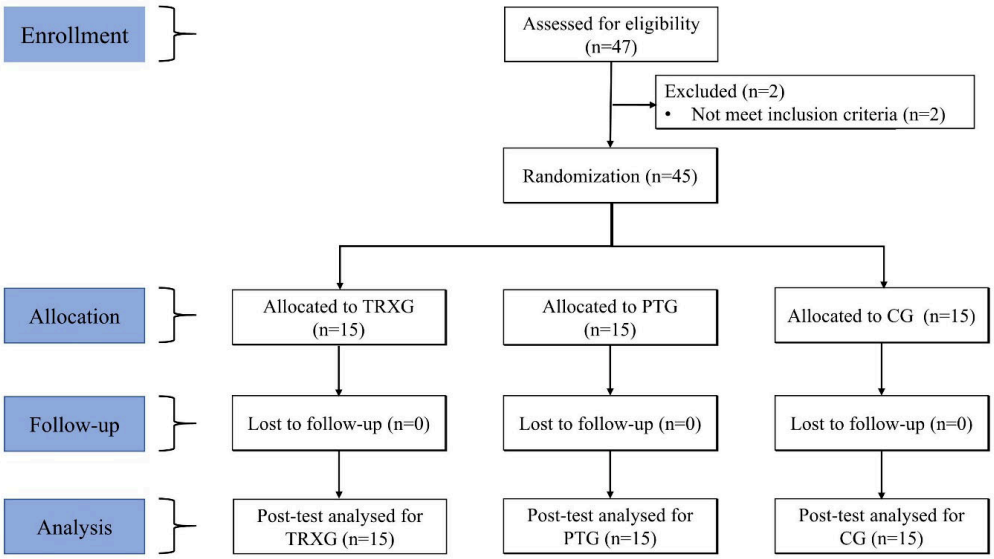

Fig. 1. Semantic representation of research study

research (Astuti et al., 2024; K V et al., 2024; Mahalingam et al., 2024) known for its dynamic training potential, offers multi-planar movements to enhance strength, endurance, and coordination. However, its impact on Kabaddi players still needs to be explored. To assess the effects of Bulgarian Bag training (BBT), and the test was carried out on an outdoor track. The participants were positioned behind the starting line with preferred leg forwarded and instructed to begin the test only upon the tester's signal. Each participant completed three timed trails, with time recorded by the timekeeper. The best performance from the three trials was selected as the final speed test score. Sufficient rest (5 minutes) interval was provided between trials to allow for full recovery.

Agility

The t-test was utilized to assess agility. The T-test was carried out in accordance with the procedure that was stated in the prior research (França et al., 2022). The participants were positioned behind the starting line with their preferred leg forward, and they were instructed to begin the test only upon the tester's signal. Starting the signal participants were run (strait run) 9.14 meters straight to the center marker. Then the participants turned left and ran (sideward run) towards the left 4.75-meter marker. Participants then make a right turn and run (sideward run) to the 9.14-meter marker, turning around to return 4.75 meters to the center marker (sideward run). Finally, the participant run (backward) towards the finish line. Participants should touch each marker as they approach it. Every participant finished three timed trails, and the timer kept track of their times. The final agility test score was determined by taking the best result out of the three trials. There was a sufficient rest period of five minutes in between every test to ensure full recovery.

Explosive Power

Vertical jump was tested using VERTEC vertical jump test, which is a valid tool to measure veridical jump (Markwell et al., 2023). vertical jump administered in line with the guidelines provided in the earlier research (Lee et al., 2020) body mass index: 22.5 kg/m^2. First, the standing arm reach on Vertec was measured based on standing height. participants stand with their feet planted firmly on the ground, their trunk held erect, and they raised their dominant arm as high as they can. When the middle finger touched the highest point, the first score was recorded. Then, with the heel resting on the ground, participants step one foot away from the wall, jump to the highest point possible, and use their hands to touch Vertec. It is advised to jump with your hands swinging for maximum reach. The vertical jump score was calculated from the initial touch (standing reach) to the maximum jump height.

Resting Heart Rate

The resting heart rate (RHR) was measured by manual radial palpation in the early hours of the morning, before proceeding with the daily activity, which was valid test to measurer the resining heart rate (Sharma & Singh, 2020). Manual radial palpation method administrated in line with the guidelines provided in the earlier research (Stankute, 2022). While doing the measurement the researcher located the radial artery at the wrist. Ones the pulse was detected, the evaluation process commenced, lasting for duration of one minute (beats per minutes).

Vital Capacity

Vital capacity was measured using spirometer and the values expressed in liters (Govindasamy et al., 2024; Sukadiono et al., 2022). During the assessment, each participant was allowed three attempts to ensure accurate results. The highest value out of three trials was recorded as the final vital capacity of the participants. After each trail, the spirometer was carefully inspected and calibrated to ensure the optimal functioning before the next trail in the earlier research (Govindasamy et al., 2023).

Training Intervention Procedure

Based on the information shown in Table 1 and 2, the training intervention for both the TRXG and the PTG was intended to be gradual and planned over a period of 12 weeks. Three weeks of familiarization were provided to each group of participants before to the beginning of each training intervention. This familiarization is equivalent to fifty percent of the intensity of the actual training program. There are three sessions each week (Monday, Wednesday, and Friday) during which TRX bands and unsuspension training utilizing bodyweight are performed. TRX Squats, TRX Rows, TRX Chest Press, TRX Mountain Climbers, TRX Lunges, TRX Inverted Rows, TRX Push-ups, TRX Jump Squats, TRX Chest Fly, TRX Box Jumps and TRX Power Pulls were the exercises that were included in the training regimens. These movements were designed to target important muscle groups in the lower body and upper body. A warming for both training intervention lasting 10-15 minutes which includes general and specific warming ups and dynamic stretching, a training session lasting 45-60 minutes, and a cool-down lasting 5-7 minutes are all included in each session. Similarly, Plyometric training takes place over the course of three weekly sessions on Tuesdays, Thursdays and Saturdays. The exercises in the training regimens includes Box Jumps, Medicine Ball Overhead Throws, Tuck Jumps, Lateral Bounds, Depth Jumps, Plyometric Push-ups, Split Squat Jumps, Standing Long Jumps, Medicine Ball Slam, Single-Leg Bounds and Depth Jumps with Medicine Ball Slam. which also targeted the muscular areas in the upper and lower bodies. In the TRX training program, the intensity was predetermined by the number of repetitions, the number of sets, the number of exercises performed per session, and the difficulty of the activity. The intensity of the plyometric training was determined by several key variables, which included the number of repetitions, the number of sets, the number of exercises performed per session. Especially, for the lower body exercises, box height was progressively increased; 12 inches during 1-4 weeks, 18 inches during 5-8 weeks, and 24 inches during 9-12 weeks. Upper body training intensity was adjusted based on the weight of the medicine ball, starting with 3 kg in 1-4 weeks, 5 kg in 5-8 weeks, and 7 kg in 9-12 weeks. Participants in both the TRXG and PTG groups were given the instruction to rest for a period of 120 seconds between sets and for a period of 30-40 seconds between exercises. This was done to ensure that they had ample time to recover while still maintaining an appropriate intensity level throughout the training sessions.

Statistical Analyses

The data are presented as means with corresponding standard deviations (± SD). Normality across variables was assessed and confirmed using the Shapiro-Wilk test, while Levene's test was employed to verify the homogeneity of variance. Training-related effects were examined via a linear mixed-effects model, which was applied in the form of a repeated measures analysis of variance (ANOVA) with two factors: group (TRXG, PTG, CG) and time (pre, post). When significant group-by-time interactions were observed, post hoc comparisons using the Bonferroni correction were conducted. In cases where the assumption of sphericity was violated, as indicated by Mauchly's test, Greenhouse-Geisser corrections were applied. Partial eta squared (ηp^2) values were extracted from the ANOVA results to indicate effect sizes, and Cohen's d was calculated to assess the magnitude of differences, classified as trivial (< 0.2), small (0.2–0.59), medium (0.60–1.19), large (1.2–1.99), or very large (≥ 2.0). A predefined contrast analysis was employed to evaluate the hypothesis (H1) that both training groups (TRXG, PTG) would show more significant improvements in outcome variables compared to the control group. Specifically, we compared the control condition against the combined effect of the two training groups (TRXG and PTG). This analysis method allowed us to assess theoretical expectations in relation to observed group means, providing more nuanced insight beyond what post hoc analyses typically offer. Statistical significance was set at $p < 0.05$.

Table 1. TRX training program

Weeks	Number of Exercise per session	Volume (sets × reps)	Rest in between sets (Minutes)	Rest in between exercise (Seconds)
Week 1-4	5	3 × 6-8	2	30-40
Week 5-8	7	3 × 8-10	2	30-40
Week 9-12	9	3 × 6-10	2	30-40

Exercise: TRX Squats, TRX Rows, TRX Chest Press, TRX Mountain Climbers, TRX Lunges, TRX Inverted Rows, TRX Push-ups, TRX Jump Squats, TRX Chest Fly, TRX Box Jumps, TRX Power Pulls

Table 2. Plyometric training program

Weeks	Number of Exercise per session	Volume (sets × reps)	Rest in between sets (Minutes)	Rest in between exercise (Seconds)
Week 1-4	5	3 × 6-8	2	30-40
Week 5-8	7	3 × 8-10	2	30-40
Week 9-12	9	3 × 6-10	2	30-40

Exercise: Box Jumps, Medicine Ball Overhead Throws, Tuck Jumps, Lateral Bounds, Depth Jumps, Plyometric Push-ups, Split Squat Jumps, Standing Long Jumps, Medicine Ball Slam, Single-Leg Bounds, Depth Jumps with Medicine Ball Slam

Results

All volleyball players completed the study without any withdrawals, injuries, or missed training sessions. The results for the dependent variables from the main analysis are provided in Tables 3 and 4. The pre- and post-intervention percentage changes are illustrated in Figure 2.

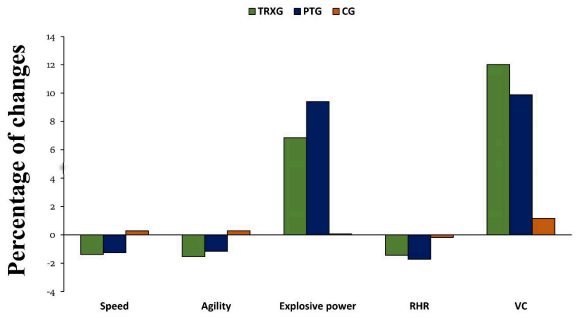

Fig. 2. Pre- and post-intervention percentage changes of outcome measures

Bio motor variables

Table 3 presents the results for bio-motor variables. A significant main effect of time was identified for speed ($p < 0.001$; $F = 13.26$, $\eta^2p = 0.240$), agility ($p = 0.003$; $F = 10.24$, $\eta^2p = 0.196$), and explosive power ($p < 0.001$; $F = 214.97$, $\eta^2p = 0.837$). However, a significant main effect of group was only noted for explosive power ($p = 0.004$; $F = 6.37$, $\eta^2p = 0.233$). Additionally, significant group-by-time interactions were observed for speed ($p = 0.005$; $F = 6.03$, $\eta^2p = 0.223$), agility ($p = 0.007$; $F = 5.64$, $\eta^2p = 0.212$), and explosive power ($p < 0.001$; $F = 54.46$, $\eta^2p = 0.722$). There were no significant main effects of group for speed ($p=0.330$; $F = 1.13$, $\eta^2p = 0.051$) or agility ($p = 0.522$; $F = 0.66$, $\eta^2p = 0.030$). Post-hoc analyses showed significant decreases from pre- to post-tests for both speed ($p < 0.001$; $d = 0.29$) and agility ($p = 0.003$; $d = 0.33$). Furthermore, post-hoc tests revealed significant improvements in explosive power for both the TRXG ($p = 0.012$; $d = 0.99$) and PTG ($p = 0.007$; $d = 1.12$), with both values under 0.05. Both TRXG and PTG demonstrated significant improvements from pre- to post-tests compared to the control group.

Physiological Variables

Table 4 summarizes the results for physiological variables. A significant main effect of time was observed for vital capacity ($p < 0.001$; $F = 34.73$, $\eta^2p = 0.453$), while the main effect of group was also significant for vital capacity ($p = 0.011$; $F = 5.06$, $\eta^2p = 0.194$). Additionally, significant group-by-time interactions were found for vital capacity ($p = 0.004$; $F = 6.42$, $\eta^2p = 0.234$). However, no

Table 3. Comparisons for changes in bio motor variables between TRX Suspension (TRXG), Plyometric Training (PTG), and control groups

Variables	Group	Mean ± SD		Paired t-test p-value	MD (95 % CI)	p (Cohen's d)		
		Baseline	After			Main effect group	Main effect time	Interaction group x time
Speed (seconds)	TRXG	7.19 ± 0.17	7.09 ± 0.19	0.022	0.09 (0.01 to 0.17)	0.330 (0.051)	<0.001 (0.240)	0.005 (0.223)
	PTG	7.14 ± 0.18	7.05 ± 0.18	<0.001	0.09 (0.01 to 0.05)			
	CG	7.19 ± 0.19	7.21 ± 0.23	0.404	-0.02 (-0.07 to 0.03)			
Agility (seconds)	TRXG	10.35 ± 0.23	10.19 ± 0.20	0.004	0.15 (0.05 to 0.25)	0.522 (0.030)	0.003 (0.196)	0.007 (0.212)
	PTG	10.36 ± 0.24	10.24 ± 0.22	0.037	0.11 (0.00 to 0.22)			
	CG	10.35 ± 0.24	10.38 ± 0.25	0.234	-0.03 (-0.09 to 0.02)			
Explosive Power (centimeters)	TRXG	42.86 ± 1.64	45.80 ± 1.78	< 0.001	-2.93 (-3.50 to -2.36)	0.004 (0.233)	<0.001 (0.837)	<0.001 (0.722)
	PTG	42.53 ± 1.64	46.53 ± 1.40	< 0.001	-4.00 (-4.62 to -3.37)			
	CG	42.77 ± 1.75	42.80 ± 1.14	0.806	-0.06 (-0.63 to 0.50)			

TRXG: TRX suspension training group, PTG: plyometric training group, CG: control group

Table 4. Comparisons for changes in physiological variables between TRX Suspension (TRXG), Plyometric Training (PTG), and control groups

Variables	Group	Mean ± SD		Paired t-test p-value	MD (95 % CI)	p (Cohen's d)		
		Baseline	After			Main effect group	Main effect time	Interaction group x time
RHR (bpm)	TRXG	74.13 ± 3.94	73.06 ± 3.84	0.320	1.06 (-1.15 to 3.28)	0.374 (0.046)	0.156 (0.047)	0.689 (0.018)
	PTG	73.46 ± 3.81	72.20 ± 3.38	0.247	1.26 (-0.98 to 3.51)			
	CG	74.40 ± 2.61	74.26 ± 3.01	0.880	0.13 (-1.72 to 1.99)			
VC (mL)	TRXG	3.41 ± 0.20	3.82 ± 0.22	<0.001	-0.40 (-0.60 to -0.20)	0.011 (0.194)	<0.001 (0.453)	0.004 (0.234)
	PTG	3.44 ± 0.17	3.78 ± 0.24	0.001	-0.34 (-0.52 to -0.15)			
	CG	3.44 ± 0.19	3.48 ± 0.20	0.405	-0.04 (-0.14 to 0.06)			

VC: vital capacity, bpm: beat per minute, mL: milliliters, TRXG: TRX suspension training group, PTG: plyometric training group, CG: control group

significant time effect was detected for resting heart rate ($p = 0.156$; $F = 2.08$, $\eta^2p = 0.047$), and no main effect of group ($p = 0.374$; $F = 1.00$, $\eta^2p = 0.046$) or group-by-time interaction ($p = 0.68$; $F = 0.37$, $\eta^2p = 0.018$) was found for resting heart rate. Post-hoc analyses indicated significant improvements in vital capacity for both the TRXG ($p = 0.022$; $d = 0.71$) and PTG ($p = 0.022$; $d = 0.68$), with p-values below 0.05. Moreover, post-hoc tests demonstrated significant pre-to-post improvements in both the TRXG and PTG when compared to the control group.

Discussion

This research compared the motor skill performance and physiological feedback of 18-24-year-old male volleyball players performing 12-week TRX suspension and Plyometric Training. The findings establish that the modes enhance other crucial compartments of performance, such as speed, agility, and explosive power. For volleyball players, increases in these motor skills are critical since quick movement, quick direction changes, and explosive power are all important for in-game success.

The TRXG and PTG groups demonstrated marked improvements regarding speed and agility. The TRXG showed a 1.39 % improvement in speed, while the PTG showed a 1.26 % improvement. Similarly, agility improved by 1.55 % in the TRXG and 1.16 % in the PTG. These results highlight how both training approaches can be applied to help athletes become more adept at responding fast and effectively on the court, which can lead to better performance during competitive play. Of the improvements, the agility enhancement underscores the need to incorporate the training programs because volleyball players often change direction to cover for fast-moving balls. A breathtaking consideration is that PTG experiences a higher increase in the magnitude of explosive power than the TRXG. Whereas the TRXG recorded a more general uplift of 6.86 percent in explosive power, the PTG recorded a much higher recovery rate of 9.41 percent. This implies that plyometric training focuses more on rapid force production than power training and thus could be more suitable for enhancing explosive power, a skill seen frequently in volleyball. Plyometric exercises, including jumps and sprints, may engage fast-twitch muscle fibers to a more significant extent than the TRX suspension exercises, mainly based on strength and steadiness. Plyometric activities might help recruit the fast-twitch muscle fibers compared to the TRX suspension exercises, which involve strength and balance exercises (Aksović et al., 2021; Chandra et al., 2023; Wang et al., 2023).

The improvements in explosive power have functional implications beyond volleyball. Since explosive power plays a crucial role in many sports that demand sudden bursts of strength—like basketball, soccer, and track events—plyometric training can be vital to training programs across various disciplines (Aksović et al., 2020, 2021). This concurs with earlier studies' findings that sound Plyometric conditioning enhances explosive performance in sporting activities involving intermittent intensive efforts within a limited timeframe (Keoliya et al., 2024b; Mancini et al., 2024). In addition, the rise in the vital capacity by 12 percent in the TRXG and 9 percent in the PTG depicts a positive allochronic adjustment in athletes' respiratory systems, resulting in increased stamina. This enhancement suggests that with training, the two programs enhance better oxygen delivery, and hence, athletes can sustain high energy output for a longer time.

This finding aligns with studies emphasizing the role of aerobic adaptations in athletic performance, especially in sports requiring sustained periods of effort (Hussein et al., 2024; Stensrud et al., 2020). Although no significant changes were observed in resting heart rates, this could indicate that a longer training duration is essential to achieve noticeable cardiovascular adaptations (Mannakkara & Finocchiaro, 2023; Parry-Williams & Sharma, 2020). Although TRX suspension and plyometric training programs significantly improve motor abilities, each method offers different advantages. Plyometric training's superior effectiveness in explosive power development indicates it primarily benefits movements that require rapid force production (Behm et al., 2024; Moran et al., 2021). Plyometric workouts may well be another effective model of training those invaluable skills since volleyball is a sport that considerably involves such aspects as repeated jumps, sprints to cover short distances, and rate turns (Keoliya et al., 2024; Watkins et al., 2021). However, TRX suspension training improves muscle strength, steadiness, and balance (Blasco et al., 2023; Khorjahani et al., 2021). This training modality involves only bodyweight movements targeting the core and stabilizer muscles for joint stabilization and overall control (Khorjahani et al., 2021; Piri et al., 2021). For volleyball players, where injury prevention and stability during dynamic movements are crucial, TRX training can serve as a practical tool for maintaining physical resilience and reducing the risk of injury (Aslani et al., 2018; Fayazmilani et al., 2022; Khorjahani et al., 2021). TRX exercises also help with general athletic development since they train several muscles simultaneously and are valuable, along with plyometrics regarding specific exercise types (Alhenawy, 2023; Moghadasi et al., 2024).

From the positive impact seen from each training method, it will significantly benefit if volleyball players integrate the TRX and plyometric exercises into their training program. A combination of both training types could train speed, agility, explosive power, and general strength, which seems apt to volleyball players as the game demands all-around physical endurance. This way, integrating TRX suspension training for enhancing the body's stability and control along with plyometric training for enhancing explosive power of the body, the athletes would come to much more improved performances on an all-around scale, which is always beneficial, especially in competitions. It would be necessary for future studies to look at the physiological and performance changes over more significant periods with these combined training schemes to pinpoint the precise lengths and intensities that would bring about the best changes in the body and, eventually, performance. Furthermore, evaluating the effects of TRX and plyometric training on the athlete's cross-sectional might help enhance the understanding of the possibility of these effects.

Conclusion

The study's conclusion reaffirms that suspension exercise, especially TRX and Plyometric Training, affects motor and physiological performance among male volleyball athletes.

Plyometric training is preferred to plyometrics for explosive power development and essential change of direction movements and jumps. On the other hand, TRX training strengthens muscular strength and postural and core muscle control and protects against physical injuries. Both methods also demonstrate increased vital capacity, which is generally significant, but no changes in resting heart rate, suggesting that longer training durations may be required to achieve cardiovascular changes. It is proposed that these training methods be incorporated to deal with the many tactical demands of volleyball to create speed, power, agility, and endurance among the athletes for competitive performance.

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Conflict of Interest

No conflict of interest was reported by the authors.

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Застосування 12-тижневої програми за методиками TRX-тренувань з власною вагою із використанням підвісних конструкцій та пліометричних тренувань: Вплив на показники біомоторних здібностей та фізіологічних адаптацій у волейболістів

Абхіджит Мурієдат[1ABCDE], Масіламані Елаяраджа[1ABCDE], Нірмал Майкл Салві[2ABCDE], Фарджана Актер Бобі[3ACD], Бекір Ерхан Орхан[4ACDE], Юні Астуті[5ACDE], Каруппасами Говіндасами[2ACDE]

[1]Пудучеррійський університет
[2]Міжнародний університет Симбіозис
[3]Міжнародний університет Даффоділ
[4]Стамбульський університет Айдин
[5]Падангський державний університет

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

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Історія питання. Задля поліпшення показників результативності волейболісти потребують поєднання фізичних і фізіологічних здібностей, а виконання TRX (Total Resistance exercises — вправи на загальний опір) тренувань з власною вагою із використанням підвісних конструкцій (петель) та пліометричних тренувань, як відомо, покращує такі здатності. Проте існує недостатньо доказів щодо порівняння ефективності застосування зазначених методів у волейболістів.

Мета дослідження. Мета дослідження полягала у вивченні впливу 12-тижневої програми за методиками TRX-тренувань з власною вагою із використанням підвісних конструкцій та пліометричних тренувань на показники біомоторних здібностей та фізіологічних адаптацій у волейболістів-чоловіків.

Матеріали та методи. У дослідженні взяли участь сорок п'ять спортсменів-чоловіків (вік: 21,91 ± 1,10) з університету Калікут, штат Керала, Індія. Учасників було розподілено на три групи: TRX-тренування з власною вагою із використанням підвісних конструкцій, пліометричні тренування та контрольна група. Перед початком і після завершення інтервенції вимірювали показники швидкості, спритності, вибухової сили, життєвої ємності легень і частоти серцевих скорочень у стані спокою. Після проведення цього етапу дані були піддані статистичному аналізу, включаючи лінійні

моделі змішаних ефектів і повторні вимірювання дисперсійного аналізу (ANOVA) з метою оцінки взаємодії між групами в залежності від часу.

Результати. Отримані дані свідчать про значне покращення показників швидкості ($p < 0,001$), спритності ($p = 0,003$) та вибухової сили ($p < 0,001$) в обох тренувальних групах, з помітною міжгруповою та часовою взаємодією. Також показано суттєве поліпшення показників життєвої ємності легень ($p < 0,001$), тоді як частота серцевих скорочень у стані спокою залишилася незмінною.

Висновки. Таким чином, доведена ефективність застосування TRX-тренувань з власною вагою із використанням підвісних конструкцій та пліометричних тренувань в контексті підвищення біомоторних здібностей, життєвої ємності легень у волейболістів, що дозволяє використовувати вищезазначені методики в якості дієвого інструменту для покращення показників результативності, не впливаючи на частоту серцевих скорочень у стані спокою.

Ключові слова: швидкість, спритність, вибухова сила, волейбол, частота серцевих скорочень у стані спокою.

Information about the authors:

Muriyedath, Abhijith: abhijithmuriyedath01@gmail.com; https://orcid.org/0009-0009-0840-9605; Department of Physical Education and Sports, Pondicherry University, R Venkat Raman Nagar, Kalapet, Puducherry 605014, India.

Elayaraja, Masilamani: elaya.cricket@gmail.com; https://orcid.org/0000-0002-0022-961X; Department of Physical Education and Sports, Pondicherry University, R Venkat Raman Nagar, Kalapet, Puducherry 605014, India.

Salvi, Nirmal Michael: nirmalsalvi@gmail.com; https://orcid.org/0000-0001-9698-9818; Department of Sports, Recreation & Wellness, Symbiosis International (Deemed University), Lavale, Mulshi, Pune, Maharashtra 412115, India.

Boby, Farjana Akter: boby.pess@diu.edu.bd; https://orcid.org/0000-0003-3168-6888; Department of Physical Education and Sports Science, Faculty of Health and Life Science, Daffodil International University, Daffodil Smart City, Birulia, Savar, Dhaka-1216, Bangladesh.

Orhan, Bekir Erhan: bekirerhanorhan@aydin.edu.tr; https://orcid.org/0000-0002-3149-6630; Faculty of Sports Sciences, Istanbul Aydin University, Halit Aydın Campus No:38, 34295 Küçükçekmece/İstanbul, Turkey.

Astuti, Yuni: yuniastuti@fik.unp.ac.id; https://orcid.org/0000-0001-6430-2938; Faculty of Sports Sciences, Universitas Negeri Padang, Jl. Prof. Dr. Hamka No.1, Air Tawar Bar., Kec. Padang Utara, Kota Padang, Sumatera Barat 25173, Indonesia.

Govindasamy, Karuppasamy: gowthamadnivog@gmail.com; https://orcid.org/0000-0002-3019-5545; Department of Sports, Recreation and Wellness, Symbiosis International (Deemed University), Hyderabad Campus, Modallaguda, Nandigama-509217, Rangareddy Dist, Hyderabad, Telangana, India.

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Building an Index System for Evaluating the Motor Health of Preschool-aged Children from the Perspective of Disciplinary Intersections: A Delphi Study

Dongxu Du[1ABCDE] and Chairat Choosakul[1CDE]

[1]Mahasarakham University

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

Corresponding Author: Chairat Choosakul, e-mail: chairat.c@msu.ac.th
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Abstract

Background. Sports health and the future of preschool children are urgent problems. However, a comprehensive and scientific evaluation index system (EIS) for assessing their sports health is lacking.

Objectives. The study aimed to elaborate an EIS for preschool children's motor health based on interdisciplinary subjects to solve the growth dilemma faced by children during their development.

Materials and methods. Sixteen interdisciplinary experts who have been engaged in sports and health education for more than 15 years participated in a Delphi study. They used a 5-point Likert scale twice to assess the importance of preset indicators and provided feedback to modify and allocate items to the EIS.

Results. After two rounds of expert consultation, a consensus was reached on the EIS, which included 6 primary and 26 secondary indicators. The coefficients for experts' familiarity (A_s), judgment (A_i), and authority (A_a) were all >0.7. The coefficients for opinion coordination (ω) were >0.7. The arithmetic mean (Mean) of the recognition and operability scores was ≥4, and the coefficients of variation (CV) were all <0.25. The harmonization coefficient (ω) for the primary indicators was 0.803, and the harmonization coefficient (ω) for the secondary indicators was 0.758 (all >0.75).

Conclusions. Accurate, reliable and scientific data were collected to develop an EIS in order to address the challenges of assessing children's motor health. The findings can serve as a reference for future instruction on preschoolers' motor health.

Keywords: Delphi technique, motor health, preschool children, evaluation research.

Introduction

In motor health, active health is the value orientation, focusing on the all-dimensional health of the entire population through scientific and regular exercise. Health is the core value, and motor is the driving force for individuals and society to seek a healthy lifestyle so as to improve bodily function, enhance the degree of psychological pleasure, enhance interpersonal relationships, and shape personality and other functions. In this manner, physiology, psychology, social adaptation, and even the morality of health can be sustained (Lu, 2022). We comprehensively controlled for the strength, endurance, speed, agility, flexibility, coordination, and balance of preschoolers in sports from the perspectives of mobility, object control, and stability skills. The World Health Organization (WHO) defines health as "not only the absence of physical disease, but also mental health, social adjustment and morality." Health promotion should be implemented at all ages because it may trigger benefits in terms of reducing the risk of, and preventing, disease (Razeghi, et al., 2020). Motor health behaviors involve issues such as a healthy diet, motor habits, sleep patterns, and exercise intensity (Anderson, et al., 2016). Physical and mental health appear to play key roles in children's typical development, with physical health encompassing cardiorespiratory fitness, flexibility, muscular strength, and muscular endurance, and mental health relating to self-esteem, anxiety, and stress (Cocca, et al., 2020). Sedentary behavior and physical inactivity are among the major modifiable risk factors for cardiovascular disease (CVD) and all-cause mortality globally. The promotion of physical activity across age groups, races, ethnicities, and

sexes is needed to improve cardiorespiratory fitness to prevent many chronic ailments, especially CVD (Lavie, et al., 2019). Family disruption – characterized by overcrowding, noise, and chaos at home – may hinder efforts to engage in a sufficient number of exercise behaviors (Kracht, et al., 2021).

In 2019, regarding children under 5 years of age, the WHO recommended in the 24th Guidelines on Physical Activity, Sedentary Behavior, and Sleep for Children that children between the ages of 3 and 4 be physically active for at least 180 minutes per day, of which at least 60 minutes should consist of moderate to vigorous physical activity. Further, children should not be sedentary for more than 1 hour per day, and they should be getting 10-13 hours of good quality sleep (WHO, 2019). Preschoolers' health-related quality of life (QoL) increases with compliance with the WHO guidelines for physical activity, sedentary behavior, and amount of sleep (Chia, et al., 2019). A comprehensive understanding of the correlations among these components will provide a foundation for protecting and improving health. Children's motor development shows a high degree of individual variability, with weight status significantly affecting motor trajectory (Coppens, et al., 2019). The emergence of individual behavior is closely tied to the environment in which it occurs and is susceptible to environmental factors (Yao, et al., 2021). Motor skills are usually categorized into two types: gross and fine motor skills. Fine motor skills include the movement of small muscles in the body, while gross motor skills encompass movement and object control (Robinson, 2010). Regular physical activity can prevent obesity and other chronic illnesses such as CVD, diabetes, cancer, hypertension, depression, and osteoporosis (Warburton, 2006). Physical activity and motor ability are closely related to preventing childhood obesity, and the relevance of motor ability to individuals, families, and the environment. Further, the socio-ecological correlates of children's mental health are multidimensional, and individual correlates are the most important predictors of mental health (Niemistö, et al., 2020). Initial competence in basic motor skills influences their acquisition and presents potential barriers to learning complex motor skills (Costa, et al., 2021). Sports coaching interventions improve the mental health, physical fitness, and physical activity levels of children and adolescents (Ho, et al., 2017). Active play also reduces stress and anxiety in children with psychological problems (Carlier et al., 2020). Exercise frequency is directly or indirectly linked to self-esteem, stress, school satisfaction, and well-being, but not depression; exercise frequency has an indirect effect on depression through stress, and increasing exercise frequency may reduce stress (Cheon & Lim, 2020). Regular physical activity can also prevent and treat non-communicable diseases (NCDs) such as heart disease, stroke, diabetes, and breast and colon cancer. It also helps prevent hypertension, overweight, and obesity and can improve mental health, QoL, and well-being (WHO, 2018).

In this study, we aimed to review current findings on children's motor health. We also intended to explore the internal contradictions caused by the ecological holism of evaluating preschool children's motor health and the reality of traditional child-rearing, as well as the external contradictions between the holistic evaluation of an idealized ecosystem and the reality of the environment. Moreover, we aimed to use the theory of the intersections of disciplines to build an evaluation index system (EIS). We should examine reasonable expectations of preschool children's motor skills for the development of their health, implement scientific motor and health education, and help teachers and parents grasp the basic laws and characteristics regarding preschool children's motor skills and health. We employed the Delphi method to construct the EIS and weight coefficients; this included calculating experts' degree of familiarity with the indicators, the basis of their judgment, their degree of authority, the extent of coordination, the consistency coefficient, and the estimation of weights (Jünger et al., 2017; Jones & Hunter, 1995).

The innovations addressed in this paper are as follows: For the challenges facing children's development in post-modern society, it is important to build a cross-disciplinary EIS for preschool children's motor health. This is significant for the future, and the global perspective advocates for continually transcending the limitations of human health and well-being. The promotion of children's health as part of the whole of humankind is impossible to disregard.

Materials and Methods

Participants

We used snowball sampling to select Delphi panel members from different regions and universities in China based on the following inclusion and exclusion criteria:

1. The inclusion criteria were as follows: (a) working in motor training, psychology, physical education, or public health; (b) more than 10 years of work experience; (c) title qualification of associate senior or higher; (d) bachelor's degree or higher; and (e) voluntary participation in this study and positive feedback.

2. The exclusion criteria were as follows: (a) unwillingness to participate for personal reasons, (b) lack of practical experience in motor health-related work, and (c) withdrawal from the study while in progress.

This study was approved by the Ethics Committee of Mahasarakham University (#497-453/2023).

Study Design

The Delphi method involves consulting experts and translates opinions into a group consensus (McPherson, et al., 2018). It is considered a flexible research technique for setting goals and organizing projects. The researcher communicates with experts by sending them online or offline questionnaires without considering their geographic location. The process of collecting experts' suggestions is independent and anonymous, ensuring that experts do not talk with each other or exchange opinions (Black, et al., 2018). We obtained accurate and reliable data through an iterative, multistage process.

Questionnaire Design

We edited the questionnaire and made it suitable for administering online using the Questionnaire Star platform, which consisted of three parts:

(1) Preamble: A brief description of the study's purpose, content, and requirements.

(2) Basic demographic information: sex, unit, title, years of experience, field of study, and highest level of education.

(3) EIS questionnaire: The experts used a 5-point Likert scale to provide feedback on the importance of each index, the basis for their judgment, their degree of familiarity, the extent of recognition, and their operability. In addition, experts could propose modifications for each index to enrich the content of the EIS.

In December 2023, we contacted the experts in different regions in person, via email, by WeChat®, or other means; the experts did not communicate with each other. We compiled the feedback from each expert and readjusted the questionnaire for the second round of consultations to further verify the accuracy of the EIS. After two rounds of expert consultation, a consensus was reached on how to improve the EIS.

Statistical Analysis

We used WPS Office 6.4 and IBM® SPSS® Statistics 26.0 to analyze the data, which we visualized using GraphPad Prism 9 software, with the level of significance set at $p < 0.05$. We measured the degree of concentration and dispersion of the experts' opinions according to the ratio of the full marks of the experts' scores (K%), the arithmetic mean (Mean), the standard deviation (s), the coefficient of variation (CV), and other indicators. We calculated the experts' positive coefficient (Cj), basis for judgment (Ai), familiarity (As), coefficient of authority (Aa), and coefficient of coordination (ω) according to the results of the consultation.

Quality Control

We strictly developed the criteria for selecting experts to ensure the scientific credibility and accuracy of the findings. The selection of experts from the same region may have led to some degree of bias in the results (Garnett, et al., 2015). Thus, we selected experts from different regions and fields of research for this study. They filled out the questionnaire online. They also carefully checked and identified problems in contacting the experts in time. We excluded incomplete questionnaires, and two researchers entered all data to ensure the quantity and quality of the completed questionnaires.

Results

Results of Analysis from the Expert Consultation

We used the Delphi method in this study and selected 14 experts in sports science, child health assessment, psychology, and education. We distributed the questionnaire for experts through WeChat®. The experts provided assessments for the 6 primary indicators and 26 secondary indicators. Their judgments were based on theoretical analyses, work experience, reference to the literature, peer knowledge, and intuitive perceptions. We categorized familiarity with each indicator into five levels: very familiar, quite familiar, moderately familiar, less familiar, and unfamiliar.

We constructed the framework of the indicator system using methods such as a literature review and group discussions with the experts. We chose indicators through consultation with 16 and 14 experts in the first and second rounds, respectively. We assigned the indicator values and established an evaluation method along with the specifications of the approach for calculating the total score. We computed the basic information of the experts, along with the positivity coefficient, level of familiarity, judgment coefficient, level of authority, degree of coordination, and coefficient of variation.

Expert Demographics

We selected experts who specialize in sports training, assessing physical fitness, psychology, physical education, school sports, and childhood sports. Among the 14 experts (who answered the second round of questionnaires), there were 10 males and 4 females, all with a minimum of a bachelor's degree and holding titles of associate professor or higher. They met the basic requirements of the relevant professional fields. Seven experts held senior positions, accounting for 50%, and seven held associate professor positions, comprising 50%. All experts had more than 15 years of work experience. Nine had doctoral degrees (64.3%), three had master's degrees (21.4%), and two had bachelor's degrees (14.3%). They engaged in research on children's medicine and educational psychology (42.9% of the sample), whereas those involved in physical education and sports training accounted for 57.1%. All 14 experts were familiar with the comprehensive assessment of children's sports and health, with 10 (71.4%) being very familiar with it.

The Coefficient of Expert Positivity

The coefficient of expert positivity reflects the degree of cooperation among experts on this research project. This can be evaluated using the response rate of expert consultation. To some extent, the magnitude of the coefficient for expert positivity reflects the reliability of the results from the consultation. The formula for calculating the coefficient is shown in Formula 1:

$$C_j = M_j / M \quad (1)$$

where M_j is the number of questionnaires recovered from the experts, and M is the number of questionnaires distributed.

In the first round of consultation with experts, 16 questionnaires were distributed; 14 effective ones were collected, resulting in a positivity coefficient of 87.5%. In the second round of consultation with experts, 14 questionnaires were distributed, and all 14 were collected, resulting in a positivity coefficient of 100%. The positivity coefficients for both rounds of consultation were relatively high, indicating a good level of cooperation among the experts.

Level of Authority: Experts' Opinions

An expert's level of authority is generally determined by two factors: his/her level of expertise and the basis for his/her judgments, denoted as Ai, and his/her familiarity with the problem, represented by As. The formula for calculating the degree of authority is displayed in Formula 2:

$$A_a = (A_i + A_s)/2 \quad (2)$$

where A_s is the coefficient for the expert's familiarity, A_i is the coefficient for the expert's judgment, and A_a is the coefficient for the expert's authority.

The expert's level of authority is primarily based on self-assessment and can sometimes be mutually evaluated. We adopted a self-assessment method in which experts rated their familiarity with and the basis for judging the evaluation indicators. Table 1 presents the criteria and the indicators for familiarity and the basis of judgment (Sun, 2005).

Table 1. Assignment table for experts' assessments

Level of familiarity	Scores	Basis of judgment	Scores
Extremely familiar	1.0	Theoretical foundation	1.0
More familiar	0.8	Working experience	0.8
Generally familiar	0.6	Bibliography	0.6
Less familiar	0.4	Peer understanding	0.4
Very unfamiliar	0.2	Intuitive feeling	0.2

(1) The coefficient for experts' familiarity

We used the coefficient for experts' familiarity, denoted by As, to represent the experts' level of familiarity with the primary indicators. According to the statistical results of familiarity scores for the primary indicators, experts' level of familiarity with the primary indicators was above 0.7 (see Table 2). Except for a few experts who rated themselves as being generally familiar, the rest described themselves as either extremely familiar or more familiar. This indicated that the experts were familiar with the primary indicators. The coefficients for their familiarity with the primary indicators, in descending order, are as follows: physical health, motor ability, mental health, motor health behavior, motor health environment, and social and emotional competence.

According to the statistical results of the familiarity scores for the secondary indicators, experts' familiarity with the secondary indicators was above 0.7 (see Table 3). There are two indicators rated as very unfamiliar, one as less familiar, and a few as generally familiar. However, most indicators are rated as extremely familiar and more familiar. This suggests that the experts were familiar with the secondary indicators.

(2) The coefficient for experts' judgment

We used the coefficient for experts' judgment, denoted by Ai, to represent the extent to which the judgment criteria influenced the experts. According to the statistical results of the scores of the judgment coefficient for the primary indicators (Table 2), all coefficients were greater than 0.7. This implies that the judgment criteria had a significant impact on the experts. The main basis for their judgment is theoretical analysis and work experience, with some input from the literature and peer understanding. Hence, we deemed the judgment criteria to be relatively reliable. The coefficients for expert judgment regarding the primary indicators, in descending order, are motor ability, physical health, social and emotional competence, mental health, motor health behavior, and motor health environment.

Based on the statistical results of the scores of the judgment coefficient for the secondary indicators (Table 3), all coefficients were greater than 0.7. This implies that the judgment criteria had a significant impact on the experts. The main basis for experts' judgment is theoretical analysis and work experience, with some input from the literature and peer understanding. Additionally, some judgments are based on intuitive feelings. This suggests that the judgment criteria were reliable.

(3) The coefficient for experts' authority

Based on the coefficients for familiarity and judgment regarding the primary indicators, calculated according to Formula 2, we calculated the coefficients for experts' authority regarding the primary indicators (Table 2). The coefficients for experts' authority regarding the primary indicators were all greater than 0.7, indicating that the 14 experts had a high level of authority regarding the primary evaluation indicators. We deemed the experts' opinions to be highly reliable.

Table 2. Experts' familiarity, judgment, and authority regarding the first-level indicators

Indicators	A_i	A_s	A_a
A: MA	0.83	0.84	0.84
B: PH	0.83	0.86	0.84
C: MH	0.79	0.83	0.81
D: SEC	0.80	0.77	0.79
E: MHE	0.76	0.81	0.79
F: MHB	0.77	0.83	0.80

Note: A_s, coefficient for experts' familiarity; A_i, coefficient for experts' judgment; A_a, coefficient for experts' authority; MA = motor ability; PH = physical health; MH = mental health, SEC = social and emotional competencies; MHE = motor health environment, MHB = motor health behavior.

Table 3. Experts' familiarity, judgment, authority regarding the secondary indicators

Indicators	A_i	A_s	A_a
A1: Speed	0.83	0.83	0.83
A2: Strength	0.83	0.77	0.80
A3: Coordination	0.83	0.84	0.84
A4: Flexibility	0.81	0.81	0.81
A5: Balance	0.81	0.83	0.82
B1: Body shape	0.81	0.90	0.86
B2: PP	0.80	0.76	0.78
C1: EH	0.83	0.80	0.81
C2: Self-esteem	0.84	0.79	0.81
C3: Families	0.81	0.79	0.80
C4: SC	0.81	0.76	0.79
C5: Schools	0.86	0.83	0.84
D1: SO	0.77	0.76	0.76
D2: RS	0.77	0.76	0.76
D3: DM	0.83	0.74	0.79
D4: SA	0.77	0.79	0.78
D5: SM	0.81	0.77	0.79
E1: SP	0.79	0.74	0.76
E2: CE	0.77	0.76	0.76
E3: SI	0.76	0.73	0.74
E4: SE	0.83	0.84	0.84
E5: FE	0.86	0.86	0.86
F1: MB	0.79	0.83	0.81
F2: Lifestyle	0.83	0.76	0.79
F3: PB	0.86	0.77	0.81
F4: Adaptation	0.77	0.79	0.78

Note: A_s = coefficient for experts' familiarity; A_i = coefficient for experts' judgment; A_a = coefficient for experts' authority; CA = coordination ability; PP = physiological perception; EH = emotional health; SC = social contact; SO = social awareness; RS = relationship skills; DM = responsive decision-making; SA = self-awareness; SM = self-management; SP = sports policies; CE = community environment; SI = sports institutions; SE = school environment; FE = family environment; MB = motor behavior; PB = psychological behavior

Based on the coefficients of familiarity and judgment for the secondary indicators, calculated according to Formula 2, we calculated the coefficients for experts' authority regarding the secondary indicators (Table 3). The coefficients for

experts' authority regarding the secondary indicators were all greater than 0.7, implying that the 14 experts had a high level of authority regarding the secondary evaluation indicators. We deemed the experts' opinions to be highly reliable.

Consistency of experts' opinions

The degree of coordination of experts' opinions reflects the magnitude of disagreement among them and is crucial for assessing the credibility of the results from the consultation. The smaller the differences in experts' opinions on the indicators, the higher the degree of coordination, indicating stronger unity and guiding significance in the opinions. We measured the degree of coordination of experts' opinions by the coefficient for the consistency of experts' opinions, ω, which reflects the level of agreement among m experts on n indicators. The value of ω ranges from 0 to 1, and the closer ω is to 1, the better the degree of coordination of expert opinions.

(1) Calculation method for the coefficient of experts' consistency

We ranked and calculated the indicators as shown in Formula 3:

$$T_j = \sum_{i=1}^{m} R_{ij} \quad (3)$$

In this formula, T_j represents the sum of rankings for the j-th indicator; R_{ij} denotes the ranking given by the i-th expert to the j-th indicator, and the ranking is arranged in descending order of scores. We calculated the average rank sum of each evaluation indicator as seen in Formula 4:

$$\overline{T} = \sum_{i=1}^{n} T_j/n \quad (4)$$

In this formula, $\overline{T}$ is the average rank sum of each evaluation indicator, and T_j is the rank sum of the j-th indicator.

We calculated the sum of the squared deviations from the rank sum of all indicators based on Formula 5:

$$\sum_{j=1}^{n} d_j^2 = \sum_{j=1}^{n} (T_j - \overline{T})^2 \quad (5)$$

In this formula, $\sum_{j=1}^{n} d_j^2$ represents the sum of the squared deviations from the mean of the sum of the ranks of all indicators. We calculated the coefficient for consistency of opinions based on Formula 6:

$$\omega = \frac{12}{m^2(n^3 - n)} \sum_{j=1}^{n} d_j^2 \quad (6)$$

ω denotes the coefficient for consistency of opinions among m experts on n indicators, where m is the number of experts participating in the assessment of indicators, and n is the number of evaluation indicators. When there is the same rank, ω is corrected, as seen in Formula 7:

$$\omega = \frac{12}{m^2(n^3 - n) - m\sum_k (t_k^3 - t_k)} \sum_{j=1}^{n} d_j^2 \quad (7)$$

In this formula, t_k represents the number of identical ranks.

(2) Results of the coefficient for coordination among experts' opinions

The coefficient for coordination has values between 0 and 1. The closer it is to 1, the better the coordination among all experts in their ratings for all evaluation indicators. Conversely, a value closer to zero implies poorer coordination among experts in their ratings of all evaluation indicators, suggesting significant inconsistency among experts regarding the relative importance of various evaluation indicators. We calculated the coefficients of coordination for both the primary and secondary indicators based on the results of the two rounds of consultation with the experts. After these two rounds, the coefficient of coordination for the primary indicators was 0.803, and that for the secondary indicators was 0.758. Both ω values were greater than 0.7, implying good consistency among the experts' opinions and stable evaluation outcomes (see Table 4). A coefficient for experts' authority >0.7 is considered reliable (Long et al., 2016).

Table 4. Coefficients of coordination among experts on various evaluation indicators

Indicator	Coefficients of coordination (ω)
Primary indicators	0.803
Secondary indicators	0.758

Constructing the framework of the EIS

Principles of system integrity

Following the principles of the ecosystem, Fig. 1 indicates that motor ability, physical health, psychological health, social and emotional competence, the motor health environment, and motor health behavior are form ecological chain of elements that are interdependent, mutually influencing, mutually constraining, and mutually reinforcing. We held two rounds of consultation with experts in sports science, the assessment of children's health, medical psychology, and pedagogy using symposiums, brainstorming, discussions, multiple interviews, and other forms of addressing the topic. We explored the initial proposed indicators at all levels article by article. Combined with views on the indicators (whether there is a different opinion or proposal), we put forward the modification, deletion, or replacement of the proposal and made adjustments accordingly in order to establish the preliminary expert consultation for the proposed EIS.

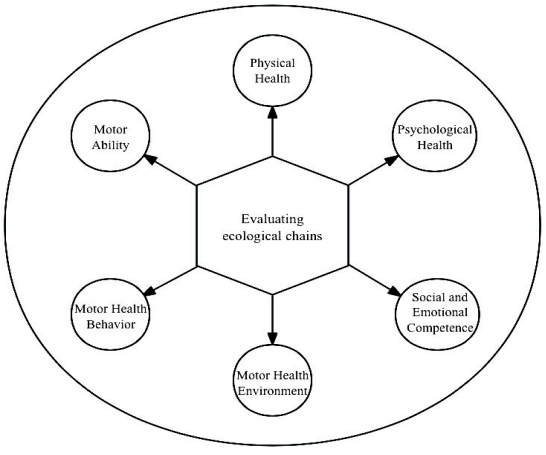

Fig. 1. Principles of system integrity

Following the principles of feasibility and emphasis on key aspects, we initially proposed categorizing an EIS for the motor health of preschool children. This system includes six primary indicators: motor ability, physical health, mental health, social and emotional abilities, the motor health environment, and motor health behavior. Motor ability is comprised of seven secondary indicators: speed, strength, endurance, flexibility, coordination, balance, and agility. Physical health includes three secondary indicators: body shape, physical function, and physiological perception. Mental health comprises five secondary indicators: emotional health, self-esteem, family interactions, social functioning, and school roles. Social and emotional abilities consist of five secondary indicators: social awareness, relationship skills, responsible decision-making, self-awareness, and self-management. The motor health environment includes six secondary indicators: sports policies, the community environment, sports facilities, the school environment, parent-child activities, and the family environment. Motor behavior includes seven secondary indicators: outdoor activities, sports behavior, hobbies, lifestyle, psychological behavior, exercise intensity, and social adaptation.

The selection of the evaluation indicators

We identified evaluation indicators for the motor health of preschool children aged 3-6 years using a questionnaire administered to experts. Based on the experts' opinions regarding the degree of acceptance, operability, and importance of each indicator, they could choose from a scoring standard of 1–5 points. As for the degree of acceptance and operability, 5 = strongly agree, 4 = somewhat agree, 3 = neutral, 2 = somewhat disagree, and 1 = strongly disagree. We evaluated the results from the consultation and assessment for each indicator based on the concentration, dispersion, and coordination of experts' opinions. We evaluated the concentration and dispersion of experts' opinions based on indicators such as the percentage of full marks (K), the arithmetic mean (Mean), the standard deviation (s), and the coefficient of variation (CV). The indicator screening procedure (Cao, et al., 2017) is as follows:

(1) Percentage of full marks (K), i.e., the proportion of experts who strongly endorsed a particular indicator among the total number of experts. K ≥ 50 % indicates a high level of endorsement by experts for that indicator.

(2) Arithmetic (Mean) of the score of a particular indicator. If Mean ≥ 4, it indicates a high level of endorsement by the experts. If 3 ≤ Mean < 4, we made a judgment in conjunction with other indicators to determine whether to exclude the indicator; a Mean < 3 resulted in excluding the indicator.

(3) Coefficient of variation ($CV = s/\overline{X}$). If the CV of the score for a specific indicator is ≤ 0.25, it implies fairly good consistency among experts' opinions. If CV > 0.25, we made a comprehensive judgment based on K and $\overline{X}$ to decide whether to retain or discard a particular indicator.

(4) When two or more indicators simultaneously reflected experts' non-acceptance or difficulty with operations, or when there was significant disagreement among experts, we considered excluding that particular indicator.

Based on the acceptance and feasibility of the primary indicators from the first round of consultation with experts, we calculated the screening percentages (K), arithmetic means (Mean), and coefficients of variation (CV) of the primary indicators (Fig. 2). For the acceptance of primary indicators in the first round of consultation – except for the percentage of acceptance (42.86 %) for environmental health, which was less than 50 % – the percentages of acceptance for other primary indicators were all ≥50 %, with arithmetic means all >4 and coefficients of variation all <0.20. The feasibility and acceptance of the six primary indicators were reliable, so we did not consider indicators for deletion.

Based on the acceptance and feasibility of the secondary indicators in the first round of consultations with experts, we calculated the screening percentages (K), arithmetic means (Mean), and coefficients of variation (CV) (Table 5). In the evaluation outcomes for the operability of the secondary indicators in the first round of consultations with experts, the indicators that did not meet the criteria for evaluation of the consultation (K < 50 %) included: endurance (A3: K = 21.43 %), sensitivity (A7: K = 28.57 %), physical function (B2: K = 14.29 %), self-esteem (C2: K = 42.86 %), self-awareness (D4: K = 35.71 %), self-management (D5: K = 42.86 %), sports policy (E1: K = 42.86 %), community environment (E2: K = 35.71 %), parent-child activities (E5: K = 42.86 %), outdoor activities (F1: K = 42.86 %), hobbies (F3: K = 35.71 %), psychological behavior (F5: K = 42.86 %), and exercise intensity (F6: K = 42.86 %). Other indicators had acceptance percentages K ≥ 50 %. Endurance (A3: Mean = 2.93) and physical function (B2: Mean = 2.64) were indicators that did not meet the criteria for evaluation of the consultation regarding the arithmetic mean (Mean < 3). The indicators that met the criteria (3 ≤ Mean < 4) were sensitivity (A7: Mean = 3.29), parent-child activities (E5: Mean = 3.50), outdoor activities (F1: Mean = 3.29), hobbies (F3: Mean = 3.64), and exercise intensity (F6: Mean = 3.93). We considered deleting these five indicators based on the other indicators. The remaining indicators had arithmetic means >4. The indicators that did not meet the criteria for the coefficient of evaluation of the consultation (CV ≥ 0.25) were endurance (A3: CV = 0.41), sensitivity (A7: CV = 0.39), physical function (B2: CV = 0.46), parent-child activities (E5: CV = 0.40), outdoor activities (F1: CV = 0.50), hobbies (F3: CV = 0.33), and exercise intensity (F6: CV = 0.32). The remaining indicators had coefficients of variation of <0.25.

In the results for the recognition of secondary indicators in the first round of consultation with the experts, the indicators that did not meet the criteria (K < 50 %) included: endurance (A3: K = 14.29 %), social awareness (D1: K = 42.86 %), responsible decision-making (D3: K = 35.71 %), self-awareness (D4: K = 42.86 %), sports policy (E1: K = 42.86 %), sports institutions (E3: K = 42.86 %), parent-child activities (E5: K = 28.57 %), outdoor activities (F1: K = 35.71 %), and hobbies (F3: K = 42.86 %). Other indicators had percentages of acceptance ≥50 %. The indicator that did not meet the criterion of the arithmetic mean (Mean < 3) was endurance (A3: Mean = 2.43). The indicators that met the criteria for the arithmetic mean (3≤Mean<4) were physical function (B2: Mean = 3.93), parent-child activities (E5: Mean = 3.57), outdoor activities (F1: Mean = 3.93), and hobbies (F3: Mean = 3.86). We considered these four indicators for deletion based on the other indicators. The remaining indicators had arithmetic mean scores >4. The indicators that did not meet the criteria for the coefficient of variation

Table 5. Results of the assessment of the secondary indicators

Secondary indicators	Operability				Recognition			
	K (%)	Mean	s	CV	K (%)	Mean	s	CV
A1: Speed	57.14	4.57	0.51	0.11	57.14	4.50	0.65	0.14
A2: Strength	64.29	4.50	0.76	0.17	50.00	4.14	1.03	0.25
A3: Endurance	21.43*	2.93*	1.21	0.41*	14.29*	2.43*	1.28	0.53*
A4: CA	85.71	4.79	0.58	0.12	85.71	4.79	0.58	0.12
A5: Flexibility	57.14	4.43	0.76	0.17	57.14	4.50	0.65	0.14
A6: Balance	78.57	4.71	0.61	0.13	85.71	4.86	0.36	0.07
A7: Agility	28.57*	3.29	1.27	0.39*	57.14	4.21	1.19	0.28*
B1: Body shape	50.00	4.50	0.52	0.12	57.14	4.57	0.51	0.11
B2: Physical function	14.29*	2.64*	1.22	0.46*	50.00	3.93	1.14	0.29*
B3: PP	50.00	4.29	0.83	0.19	50.00	4.29	0.83	0.19
C1: EH	57.14	4.57	0.51	0.11	50.00	4.43	0.65	0.15
C2: Self-esteem	42.86*	4.14	0.86	0.21	50.00	4.29	0.83	0.19
C3: Families	71.43	4.57	0.76	0.17	71.43	4.57	0.76	0.17
C4: SC	57.14	4.57	0.51	0.11	50.00	4.43	0.65	0.15
C5: Schools	57.14	4.50	0.65	0.14	64.29	4.64	0.50	0.11
D1: SO	50.00	4.36	0.74	0.17	42.86*	4.29	0.73	0.17
D2: RS	57.14	4.50	0.65	0.14	50.00	4.36	0.74	0.17
D3: DM	57.14	4.43	0.76	0.17	35.71*	4.00	0.88	0.22
D4: SA	35.71*	4.00	0.88	0.22	42.86*	4.21	0.89	0.21
D5: SM	42.86*	4.07	0.92	0.23	50.00	4.29	0.91	0.21
E1: SP	42.86*	4.29	0.73	0.17	42.86*	4.29	0.73	0.17
E2: CE	35.71*	4.07	0.73	0.18	57.14	4.57	0.51	0.11
E3: SI	50.00	4.14	0.95	0.23	42.86*	4.07	0.92	0.23
E4: SE	64.29	4.57	0.65	0.14	64.29	4.57	0.65	0.14
E5: Parent-child activities	42.86*	3.50	1.40	0.40*	28.57*	3.57	1.09	0.31*
E6: FE	78.57	4.71	0.61	0.13	85.71	4.71	0.61	0.13
F1: Outdoor activities	42.86*	3.29	1.64	0.50*	35.71*	3.93	1.00	0.25
F2: MB	50.00	4.43	0.65	0.15	57.14	4.57	0.51	0.11
F3: Hobbies	35.71*	3.64	1.22	0.33*	42.86*	3.86	1.03	0.27*
F4: Lifestyle	57.14	4.50	0.65	0.14	57.14	4.50	0.65	0.14
F5: PB	42.86*	4.29	0.73	0.17	64.29	4.64	0.50	0.11
F6: Exercise intensity	42.86*	3.93	1.27	0.32*	50.00	4.07	1.27	0.31*
B2: Adaptation	50.00	4.29	0.83	0.19	50.00	4.29	0.83	0.19

Note: K (%) represents the acceptance rate, Mean is the arithmetic mean, s = variance, CV = the coefficient of variation, * implies that the indicator parameters did not meet the criteria for consultation assessment, CA = coordination ability; PP = physiological perception; EH = emotional health; SC = social contact; SO = social awareness; RS = relationship skills; DM = responsible decision-making; SA = self-awareness; SM = self-management; SP = sports policies; CE = community environment; SI = sports institutions; SE = school environment; FE = family environment; MB = motor behavior; PB = psychological behavior

(CV ≥ 0.25) were endurance (A3: CV = 0.53), sensitivity (A7: CV = 0.28), physical function (B2: CV = 0.29), parent-child activities (E5: CV = 0.31), hobbies (F3: CV = 0.27), and exercise intensity (F6: CV = 0.31). The remaining indicators had coefficients of variation of <0.25.

The secondary indicators, all seven of which we considered for exclusion, were endurance (A3), agility (A7), physical function (B2), parent-child activities (E5), outdoor activities (F1), hobbies and interests (F3), and intensity of exercise (F6). The eight indicators – whether within the range of consideration for exclusion or not – were self-esteem (C2), social awareness (D1), responsible decision-making (D3), self-awareness (D4), self-management (D5), physical activity policy (E1), community environment (E2), institutions for physical training (E3), and psychological behavior (F5). Based on the results of the current round of scores

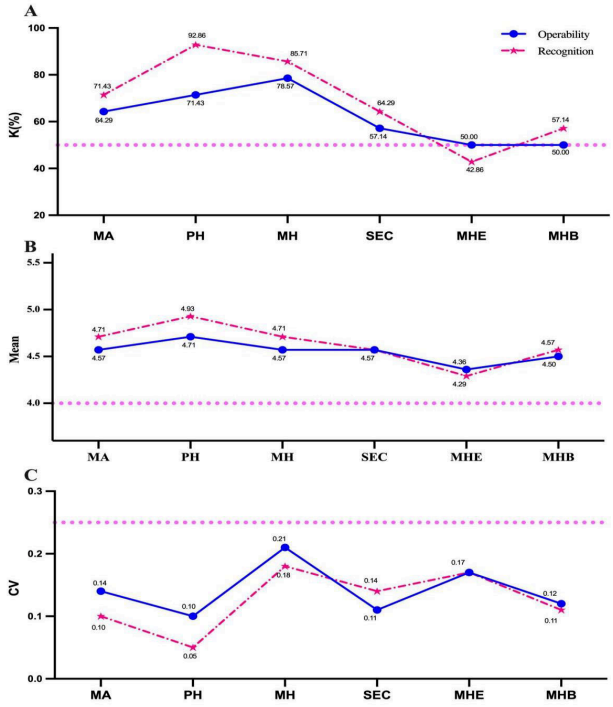

Fig. 2. Assessment map for the primary indicators

for consultation with the experts, and in accordance with the principle that "if two or more screening indicators do not meet the criteria for consultation and evaluation, consider removing the indicator," we organized the indicators by considering experts' opinions on the indicators. We excluded endurance (A3), considered to be an inappropriate indicator for preschool children. We merged parent-child activities (E5) into family environment (E6). We merged outdoor activities (F1) into exercise behavior (F2). We eliminated hobbies (F3), which we deemed an unsuitable index for motor health evaluation. We also eliminated indicators that were difficult to obtain, such as sensitivity (A7), physical function (B2), and exercise intensity (F6). We retained the rest of the indicators.

We conducted the first round of consultations with experts based on the EIS. The arithmetic mean of the scores for experts' approval and feasibility was ≥4, and the coefficient of variation was <0.25, indicating the reliability of the results and the strong feasibility of the obtained indicators. Based on these adjustments, we developed a new EIS. We proposed an EIS for motor health in preschool children aged 3-6 years. This EIS includes six primary and 26 secondary indicators (as shown in Fig. 3).

Discussion

American psychologist Urie Bronfenbrenner proposed ecological systems theory to explain how the social environment affects children's development. This theory stresses the importance of studying children in multiple environments or ecosystems in order to understand their development. According to Bronfenbrenner, children often find themselves in a variety of ecosystems, from the most intimate family setting to the larger school context,

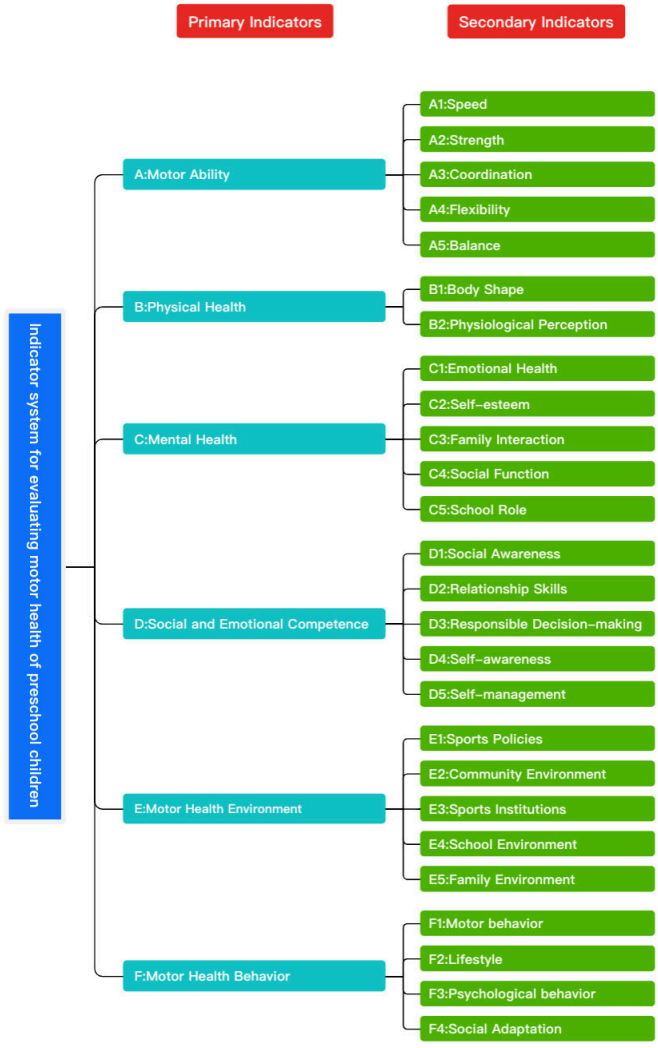

Fig. 3. Framework diagram of the EIS for the motor health of preschool children aged 3-6 years

to the broadest ecosystems that include society and culture. Human development occurs in one's immediate external environment through a process of progressively more complex interactions between active and evolving biopsychological organisms, people, objects, and symbionts (Bronfenbrenner, 2006). Hence, we followed the principle of the ecosystem, forming an ecological chain according to the cross-disciplines of athletic ability, physical health, mental health, social-emotional competence, the athletic health environment, and athletic health behaviors, which are interdependent, interact, and promote each other. We used symposia, brainstorming, focused discussions, multiple interviews, and other forms of consultations with experts to establish a preliminary EIS. Several studies have identified many factors affecting sports health (Bremner et al., 2020; Hamer et al., 2012). We compiled a relatively comprehensive EIS comprising six primary indicators of preschool children: exercise ability, physical and mental health, social and emotional competence, the motor health environment, and motor health behavior, in addition to 26 secondary indicators.

Motor ability is an important component of child development. The acquisition of basic motor skills is a prerequisite for participation in physical activity, sports, and exercise, and proficiency in motor ability contributes to an active lifestyle (Rokicka-Hebel, 2013). Children aged 2-6 years have the best opportunity to learn motor skills (LeGear et al., 2012). The development of motor skills in children is closely linked to their health (Ho et al., 2017; Lubans et al., 2010; Sorensen & Zarrett, 2014). Physical and mental health play a key role in children's typical growth (Razeghi et al., 2020; Cocca et al., 2020; Lavie et al., 2019). There is a positive correlation between nutritional-exercise behaviors and the level of health knowledge (Ayaz & Kulakçı, 2021). Moreover, problems with physical and mental health can have many negative effects on individuals, families, and society (Correll et al., 2017; Hailemichael et al., 2019), so having physical and mental health is a core element of preschoolers' development that cannot be ignored. Motor health behaviors involve topics such as healthy eating habits, exercise habits, sleep patterns, and exercise intensity (Anderson et al., 2016; Prichard et al., 2020; Reed et al., 2013). A growing body of evidence suggests that motor health behaviors not only contribute to improved physical health but can also have a significant, positive impact on children's psychology (Herring et al., 2019; Lewis et al., 2021). Social-emotional competence is a key developmental task in early childhood that significantly predicts educational and occupational achievement, health, and well-being (Rhoades et al., 2009; Schoon, 2021) and contributes to children's social success (Denham et al., 2001). The environment is an important contributor to children's motor health development (Kracht et al., 2021; Armstrong et al., 2019), and better living and learning environments give preschoolers a vital source of physical activity, leading to more physical and mental health benefits as well as better overall competence (Christian et al., 2022; Ng M et al., 2020). Hence, we constructed an EIS to assess preschool children's motor health from a cross-disciplinary perspective. In this way, we have created an opportunity to solve the theoretical challenges of assessing preschool children's motor health and to provide a reference for the future development of education regarding their motor health. In this way, we aim to improve the level of preschool children's motor health in practical teaching.

The EIS we constructed is characterized by scientific, comprehensive, and diverse features. First, we consulted experts in exercise science, the assessment of children's health, medical psychology, pedagogy, and other fields related to the topic. We did so via symposia, brainstorming, discussions on the preliminary indicators at all levels one by one, and exploring the views on the indicators (whether there are different opinions or suggestions). We proposed modifying, deleting, or replacing the proposal and made adjustments accordingly to establish the EIS. We developed the framework of the EIS by combining the cross-disciplinary knowledge of motor ability, psychology, social and emotional ability, ecosystem, and health. We also established the EIS based on a large amount of literature (Ayaz & Kulakçı, 2021; Niemistö et al., 2020; Denham et al., 2014), which implies that the EIS has a certain degree of scientific authority. Second, the experts' qualifications are reliable, and they all met the basic requirements of their professional fields by having a bachelor's degree or above, titles of associate professor or above, and more than 15 years of work experience. The experts engage in research on pediatric medicine and educational psychology (42.9 % of the sample); those engaged in physical education and athletic training comprise 57.1 %. Fourteen experts were familiar with the comprehensive evaluation of children's motor health in general or above, and ten were very familiar with it (71.4 % of the experts). This denotes that their suggestions and comments were based on rich theoretical knowledge and practical experience, making the EIS more reliable. Finally, we carried out two rounds of consultation with the experts according to the EIS; there were 16 experts in the first round and 14 experts in the second round, with positive coefficients of 80 % and 100 %, respectively. The coefficients for experts' familiarity, judgment, and authority regarding the primary and secondary indicators were >0.7. The coefficients for coordination of opinions were all >0.7. The arithmetic mean of the scores for recognition and operability was ≥4, and the coefficients of variation were all <0.25. This demonstrates that our results are reliable and that the final indicators obtained are operational. The coefficient of coordination for the primary indicators was 0.803, and that of the secondary indicators was 0.758, both of which were greater than 0.75. This implies that the consistency of the experts' opinions was good, and the estimation of the indicators' weights was stable and reliable.

This study has several limitations. First, we relied on multidisciplinary intersections and used convenience sampling to recruit only 16 experts in different fields from 10 universities in different regions. This may have led to sampling bias. In future studies, stratified random sampling should be considered to increase the authority of representative experts. Second, we constructed an EIS, which led to an unclear method for collecting data. To capture the characteristics and current status of preschool children's motor health, future studies should measure the indicator system for their motor health or develop appropriate scales to obtain reliable data for analysis. Third, we could not determine a causal relationship between the indicators. Thus, to explore the relationship between the factors affecting preschool children's motor health, future studies need to establish a structural equation model of it, validate the model's scientific validity, and use regression analysis to establish a linear functional relationship between the indicators of preschool children's motor health. Fourth, future research should simultaneously assign weights to decision-making indicators based on the intrinsic laws between the indicator data and experts' experience, which can be more reasonably applied to the practice of evaluating preschool children's motor health.

Conclusions

In sum, through the cross-disciplinary construction of an EIS for preschool children's motor health, the indicators are more operable and have better consistency from a scientific standpoint and based on experts' opinions. This creates an opportunity to solve the problem using the theory on the evaluation of preschool children's motor health. This study provides a reference for the future development of education on preschool children's motor health to improve motor health in practical teaching.

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Conflicts of interest

We declare that there are no conflicts of interest.

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Побудова індексної системи щодо оцінки стану рухового розвитку дітей дошкільного віку з точки зору дисциплінарних взаємозв'язків: Дельфійське дослідження

Дунсю Ду[1ABCDE], Чайрат Чусакул[1CD]

[1]Махасаракхамський університет

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

Реферат. Стаття: 12 с., 5 табл., 3 рис., 47 джерел.

Історія питання. Питання стану спортивної підготовки та майбутнього розвитку дітей дошкільного віку є актуальними проблемами. Однак бракує комплексної та науково обґрунтованої індексної системи оцінювання (ІСО) для визначення рівня їхнього стану спортивної підготовки.

Мета дослідження. Це дослідження мало на меті розробити ІСО щодо стану рухового розвитку дітей дошкільного віку на основі міждисциплінарних предметів для розв'язання проблематики зростання, з якою стикаються діти в процесі свого розвитку.

Матеріали та методи. Шістнадцять міждисциплінарних експертів, які понад 15 років залучені до сфери спортивної та оздоровчої освіти, взяли участь у дослідженні за методом Дельфі. Вони двічі використовували 5-бальну шкалу Лайкерта для оцінки важливості попередньо встановлених показників і надавали зворотний зв'язок з метою модифікації та розподілу пунктів в ІСО.

Результати. Після проведення двох раундів експертних консультацій було досягнуто консенсусу щодо ІСО, яка включала 6 первинних та 26 вторинних показників. Коефіцієнти обізнаності експертів (A_s), судження (A_i) та авторитетності (A_a) становили >0,7. Коефіцієнти узгодженості думок (ω) становили >0,7. Середнє арифметичне значення (Mean) балів щодо розпізнавання та функціональності склало ≥4, а коефіцієнти варіації (CV) дорівнювали <0,25. Коефіцієнт гармонізації (ω) для первинних показників становив 0,803, а коефіцієнт гармонізації (ω) для вторинних показників склав 0,758 (всі > 0,75).

Висновки. Для розроблення ІСО було зібрано достовірні, надійні та науково обґрунтовані дані, спрямовані на розв'язання проблеми щодо оцінки стану рухового розвитку дітей дошкільного віку. Отримані результати дослідження можуть слугувати основою для подальших інструкцій щодо вивчення стану рухового розвитку дошкільнят.

Ключові слова: метод Дельфі, стан рухового розвитку, діти дошкільного віку, оцінювальне дослідження.

Information about the authors:

Du, Dongxu: 726303420@qq.com; https://orcid.org/0009-0000-6732-6206; Department of Health and Sport Science, Faculty of Education,Mahasarakham University, Mahasarakham Province, 44000, Thailand.

Choosakul, Chairat: chairat.c@msu.ac.th; https://orcid.org/0000-0002-0850-142X; Department of Health and Sport Science, Faculty of Education, Mahasarakham University, Mahasarakham Province, 44000, Thailand.

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Clarifying Gender Differences in Psychological Skills and Aggression among University Athletes: A Cross-Cultural Comparison of Indicators between Individuals from Delhi and Baghdad

Ahmed Jabbar Abiyra[1ABCDE], Sandeep Tiwari[1ABCDE], Sandhya Tiwari[1ABCDE] and Mir Ahsan Ul Haq[1ABCDE]

[1]University of Delhi

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

Corresponding Author: Mir Ahsan Ul Haq, e-mail: ehsaanmeer1@gmail.com
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Abstract

Background. Psychological skills and aggression are pivotal in athletic performance, influenced by both gender and cultural contexts. These factors are shaped by individual differences and cultural influences, they are essential to the development and use of these skills by athletes in sports.

Objectives. This study aimed to evaluate the differences in psychological skills and aggression levels across gender and university, providing insights into the psychological profiles of athletes within distinct cultural contexts.

Materials and methods. The study involved 300 athletes from the University of Delhi, India, and the University of Baghdad, Iraq, aged 18 to 30 years. Each university contributed 150 athletes, evenly divided by gender (75 males and 75 females). The participants were selected using non-probability quota and purposive sampling methods. Psychological skills were assessed using the Psychological Skills Inventory for Sports (PSIS), while aggression levels were measured with the Sports Aggression Questionnaire. Data collection occurred in a controlled environment under the supervision of trained researchers. Statistical analyses included a two-way ANOVA and Pearson correlation coefficients, utilizing SPSS software.

Results. Significant differences in psychological skills and aggression levels were observed across universities and genders. According to the results obtained, University of Delhi athletes showed higher psychological skills (PS: 154.83 ± 18.50) compared to University of Baghdad athletes (PS: 109.83 ± 26.05). Furthermore, male athletes from Delhi exhibited greater aggression (44.41 ± 10.35) than their Baghdad counterparts (37.93 ± 4.20). A two-way ANOVA revealed that player type significantly influenced psychological skills ($F = 300.47$, $p = 0.01$) and aggression ($F = 71.54$, $p = 0.01$). Gender also significantly impacted Anxiety Control ($F = 8.64$, $p = 0.01$) and Foul Play ($F = 4.94$, $p = 0.05$). A weak positive correlation ($r = 0.284$, $p = 0.01$) was identified between psychological skills and aggression, suggesting a slight tendency for increased psychological skills to correspond with higher aggression levels.

Conclusions. These findings underscore the importance of considering both gender and university context when evaluating psychological skills and aggression in athletes. The insights derived from this study can inform the development of targeted training and support strategies to enhance athlete performance and well-being.

Keywords: psychological skill, aggression, gender differences, university athletes, cross-culture.

Introduction

Sports psychologists play a crucial role in enhancing both the growth of athlete's minds and bodies (Schinke et al., 2018). They work in various capacities, including research, instruction, and consultation with players and coaches. Their expertise extends beyond traditional sports science, incorporating specialized psychological training to help athletes develop mental skills that improve performance (Birrer & Morgan, 2010). Despite the recognized importance of psychological strategies in sports, they have historically not received the attention they deserve, particularly when it comes to teaching vital life skills via athletics, especially

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to young people who are at-risk. Programs led by sport psychologists have demonstrated the value of using sports as a vehicle for both personal and athletic development, highlighting the need for specialized training to impart life skills to underprivileged youth (Danish & Nellen, 1997).

Aggression, a significant aspect of sports, is often fueled by intense competition, high-conflict situations, and the entertainment value of certain sports (Alexandra et al., 2015; Chernozub et al., 2018; Lisenchuk et al., 2019). It is a fundamental characteristic of human behavior, serving as a means for individuals to affirm their self-worth and identity. In many sports, particularly contact sports like martial arts and football, aggression becomes a necessary tool for achieving success (Korobeynikov et al., 2019; Tushchenko et al., 2019). Trainers often reinforce aggressive behavior by encouraging athletes to push through challenging situations to benefit the team (Syrmpas et al., 2018). Over time, aggression can become ingrained in an athlete's behavior, contributing to favorable competitive outcomes. However, the continuous reinforcement of aggression may also lead to increased personality conflicts, as athletes internalize these aggressive traits not only in sports but also in other aspects of their lives (Petrovska et al., 2020).

In addition to aggression, psychological skills such as self-confidence, motivation, and mental resilience are critical factors influencing an athlete's success. Psychological traits can be as crucial as physical and technical abilities in determining performance outcomes (Demirci & Phytanza, 2021; Phytanza et al., 2021). Coaches often recognize a winning mindset and self-confidence as key attributes that successful athletes must develop (Van Rossum, 1996). Mental training, including techniques like mental imagery, rehearsal and visualization, has been recognized as an effective strategy to enhance athletic performance (Durand-Bush & Salmela, 2002; Rahman & Islam, 2021). Motivation is also a significant driver in training programs, as it propels athletes to engage in the actions necessary for developing critical psychological skills (Menegassi et al., 2018). Consequently, self-confidence and motivation often serve as key indicators for distinguishing between athletes who achieve success and those who do not (Purwanto et al., 2021; Sheldon et al., 2013).

Gender disparities in psychological skills and aggression are a central focus of sports psychology. Research have indicated that male athletes tend to score higher on psychological skills than female athletes, even in high-intensity sports like basketball, soccer, and swimming, even when both have comparable experience levels (Burhaein et al., 2020). Researchers Katsikas et al., (2009) suggest that gender plays a crucial role in determining psychological aptitude, with male athletes often exhibiting higher levels of aggression and assertiveness, which positively impact their performance in contact sports. On the other hand, female athletes often demonstrate greater mental resilience and adaptability, particularly in non-contact sports. Understanding these gender differences is essential for developing psychological training programs tailored to the specific needs of male and female athletes.

This study aims to explore the relationship between gender, psychological skills, and aggression among university athletes from Delhi, India, and Baghdad, Iraq. These two regions offer distinct socio-economic and cultural landscapes that shape the psychological traits and behaviors of athletes. Delhi University's emphasis on competitive athletics contrasts with the socio-political challenges faced by athletes at Baghdad University, which may influence their psychological and behavioral responses in sports. By examining factors such as mental rehearsal, anxiety management, and aggression control, For athletes across these two cities, this study looks for trends that might guide the creation of specialized training plans, coaching techniques, as well as mental health support networks.

Materials and Methods

Study participants

The study involved a sample of 300 athletes aged between 18 and 30 years, comprising 150 players from University of Baghdad and 150 players from University of Delhi. Each university's sample included 75 male players and 75 female players. Participants were selected using a non-probability quota and purposive sampling method to ensure representation from both universities. Care was taken to include only complete and clear responses, resulting in the final selection of 300 male and female players from both India and Iraq.

Study Organization

Standardization of methods was achieved by conducting data collecting in a controlled setting. Participants underwent assessments for Psychological Skills and Aggression using validated instruments. The Psychological Skills Inventory for Sports (Mahoney et al., 1987) consists of 60 items measuring six Psychological Skills: Achievement Motivation, Goal Setting, Anxiety Control, Maintaining Confidence, Concentration, and Mental Rehearsal. The Sports Aggression Questionnaire (Makarowski, 2013) includes 15 statements assessing three aggression factors: Go-Ahead, Foul Play, and Assertiveness, using a five-point Likert scale.

The researcher administered the Psychological Skills Test and Aggression Test, to the selected participants from both universities. Testing sessions were organized to ensure consistency, and all participants provided written informed consent before participation. Data collection was supervised by trained researchers to maintain accuracy throughout the process.

Statistical Analyses

Data analysis was performed using SPSS software. Descriptive statistics, including means and standard deviations, were calculated for all psychological skills and aggression measures. A two-way ANOVA was utilized to assess the effects of types of players and gender on the dependent variables, with post-hoc tests applied where necessary. Pearson's correlation coefficient was employed to examine the relationships between psychological skills and aggression, with a significance level set at 0.05 for all statistical tests to ensure the reliability of the results.

Results

The following Table 1 presents descriptive statistics (mean ± standard deviation) of psychological skills among sports majors from the University of Baghdad and the Uni-

Table 1. Descriptive statistics (mean + SD) of psychological skills among sports majors

Subjects	n	PS	AM	GS	AC	MC	CON	MR
Male Athletes (BU)	75	107.48 ± 26.87	16.94 ± 6.33	17.21 ± 6,27	18.45 ± 4.76	17.50 ± 4.48	18.90 ± 4.31	18.46 ± 7.22
Female Athletes (BU)	75	112.18 ± 25.17	17.65 ± 6.87	17.88 ± 6.39	20.00 ± 5.04	17.38 ± 4.80	20.88 ± 5.18	19.38 ± 6.06
All Athletes (BU)	150	109.83 ± 26.05	17.30 ± 6.60	17.54 ± 6.32	19.22 ± 4.95	17.44 ± 4.63	19.89 ± 4.85	18.42 ± 6.64
Male Athletes (DU)	75	151.45 ± 18.53	26.50 ± 4.94	27.08 ± 3.36	18.84 ± 4.24	24.08 ± 3.47	26.84 ± 3.70	28.06 ± 4.40
Female Athletes (DU)	75	158.21 ± 17.95	28.36 ± 4.87	27.98 ± 3.14	20.33 ± 3.73	24.89 ± 3.34	27.56 ± 3.65	28.26 ± 4.18
All Athletes (DU)	150	154.83 ± 18.50	27.43 ± 4.97	27.53 ± 3.28	19.58 ± 4.05	24.48 ± 3.42	27.20 ± 3.68	28.16 ± 4.28
All Male Athletes	150	129.46 ± 31.87	21.72 ± 7.42	22.14 ± 7.05	18.64 ± 4.50	20.79 ± 5.18	22.87 ± 5.64	23.26 ± 7.66
All Female Athletes	150	135.20 ± 31.74	23.00 ± 8.00	22.93 ± 7.13	20.16 ± 4.42	21.14 ± 5.58	24.22 ± 5.58	23.32 ± 7.17
Overall	300	132.33 ± 31.88	22.36 ± 7.73	22.54 ± 7.09	19.40 ± 4.52	20.96 ± 5.38	23.54 ± 5.64	23.29 ± 7.41

Key: PS: Psychological Skills; AM: Achievement Motivation; GS: Goal Setting; AC: Anxiety Control; MC: Maintaining Confidence; CON: Concentration; MR: Mental Rehearsal; BU: University of Baghdad; DU: University of Delhi

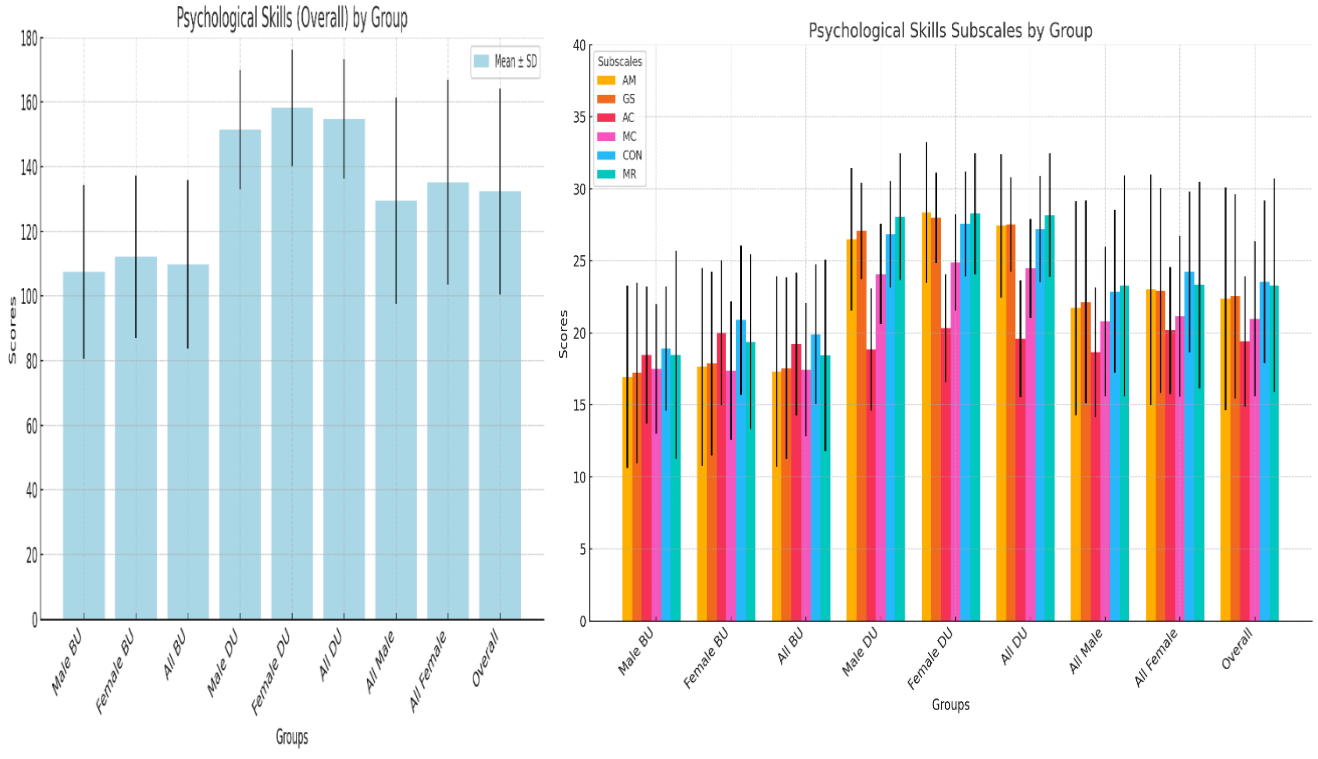

Fig. 1. Comparison of psychological skills and related traits across university and gender group

versity of Delhi, segmented by gender, while Figure 1 illustrates the corresponding mean and standard deviation scores.

The following Table 2 presents descriptive statistics (mean ± standard deviation) of aggression levels among sports majors from the University of Baghdad and the University of Delhi, segmented by gender, while Figure 2 illustrates the corresponding mean and standard deviation scores.

Table 3 presents the results indicating that Types of Players had a significant effect on PS ($F = 300.47$, $p = 0.01$), AM ($F = 227.03$, $p = 0.01$), GS ($F = 294.62$, $p = 0.01$), MC ($F = 223.57$, $p = 0.01$), CON ($F = 220.67$, $p = 0.01$), and MR ($F = 225.92$, $p = 0.01$), while Gender significantly influenced PS ($F = 4.87$, $p = 0.05$), AC ($F = 8.64$, $p = 0.01$), and CON ($F = 7.49$, $p = 0.01$). Comparing these findings with the descriptive statistics in Table 1, the higher mean scores

Table 2. Descriptive statistics of aggression among sports majors

Subjects	n	Aggression	Go-Ahead	Foul Play	Assertiveness
Male Athletes (BU)	75	37.93 ± 4.20	12.22 ± 5.40	13.86 ± 2.57	11.84 ± 4.36
Female Athletes (BU)	75	35.81 ± 4.82	11.40 ± 6.40	12.46 ± 2.27	11.94 ± 4.84
All Athletes (BU)	150	36.87 ± 4.63	11.81 ± 5.92	13.16 ± 2.52	11.89 ± 4.59
Male Athletes (DU)	75	44.41 ± 10.35	15.30 ± 4.77	13.93 ± 4.16	15.17 ± 4.83
Female Athletes (DU)	75	43.56 ± 7.99	15.20 ± 4.32	13.60 ± 4.05	14.76 ± 3.70
All Athletes (DU)	150	43.98 ± 9.22	15.25 ± 4.53	13.76 ± 4.09	14.96 ± 4.29
All Male Athletes	150	41.17 ± 8.52	13.76 ± 5.31	13.90 ± 3.44	13.50 ± 4.88
All Female Athletes	150	39.68 ± 7.64	13.30 ± 5.77	13.03 ± 3.32	13.35 ± 4.52
Overall	300	40.43 ± 8.11	13.53 ± 5.54	13.46 ± 3.41	13.43 ± 4.70

Note: Values are expressed as means standard deviations

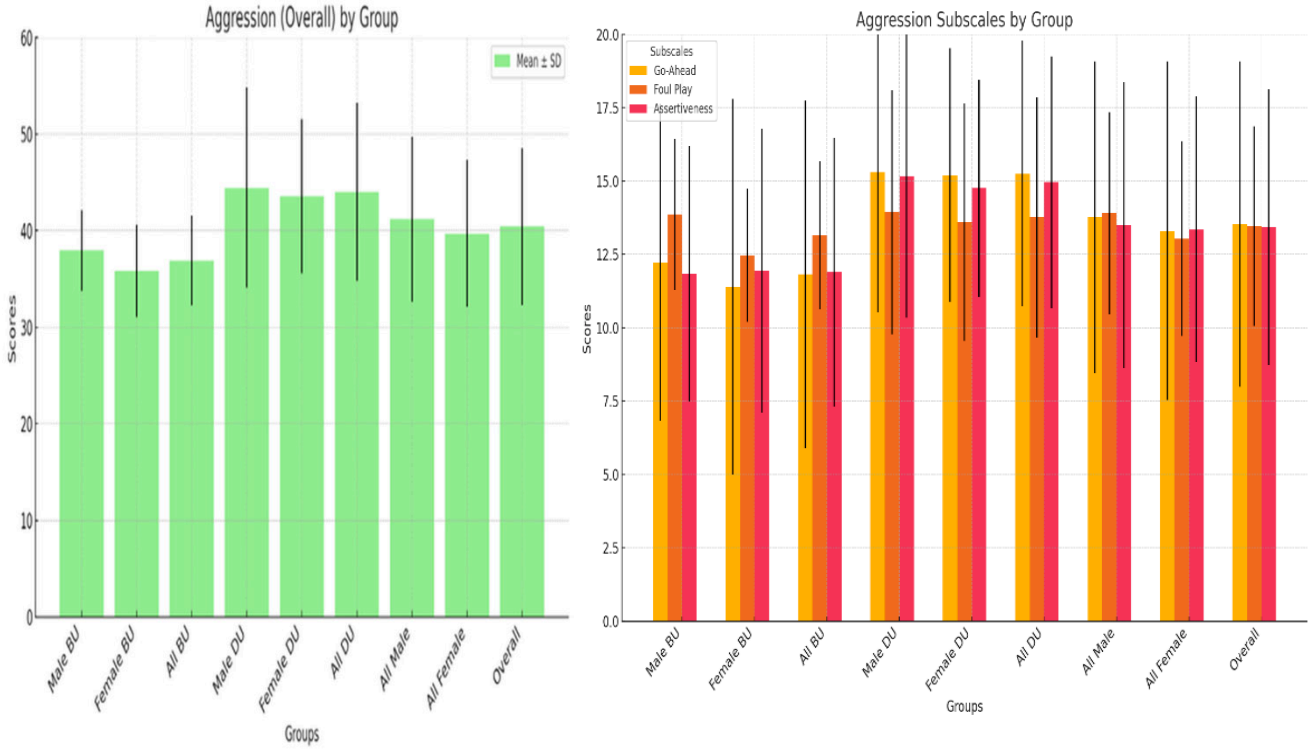

Fig. 2. Comparison of aggression and related traits across university and gender groups

for University of Delhi students across all psychological skills align with the significant effects of Types of Players, while the significant influence of Gender on AC corresponds with the higher mean scores for female students, highlighting the importance of both player type and gender in understanding psychological skills among sports majors.

Table 4 presents a summary of a two-way ANOVA conducted to assess the effects of Types of Players (A) and Gender (B) on various dimensions of aggression among sports majors, including Aggression, Go-Ahead, Foul Play, and Assertiveness. The results indicate that Types of Players had a significant effect on Aggression ($F = 71.54$, $p = 0.01$), Go-Ahead ($F = 31.77$, $p = 0.01$), and Assertiveness ($F = 35.57$, $p = 0.01$), while Gender significantly influenced Foul Play ($F = 4.94$, $p = 0.05$). The interaction between Types of Players and Gender was not significant for any of the aggression

Table 3. Summary of two-way ANOVA of psychological skills among sports majors

Variables	Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
PS	Types of Players (A)	151875.00	1	151875.00	300.47	0.01
	Gender (B)	2465.33	1	2465.33	4.87	0.05
	(A x B)	79.05	1	79.05	0.15	NS
AM	Types of Players (A)	7701.33	1	7701.33	227.03	0.01
	Gender (B)	122.88	1	122.88	3.62	NS
	(A x B)	24.65	1	24.65	0.72	NS
GS	Types of Players (A)	7480.01	1	7480.01	294.62	0.01
	Gender (B)	46.41	1	46.41	1.82	NS
	(A x B)	1.08	1	1.08	0.04	NS
AC	Types of Players (A)	9.72	1	9.72	0.48	NS
	Gender (B)	173.28	1	173.28	8.64	0.01
	(A x B)	0.05	1	0.05	0.03	NS
MC	Types of Players (A)	3717.12	1	3717.12	223.57	0.01
	Gender (B)	9.01	1	9.01	0.54	NS
	(A x B)	16.33	1	16.33	0.98	NS
CON	Types of Players (A)	4004.05	1	4004.05	220.67	0.01
	Gender (B)	136.01	1	136.01	7.49	0.01
	(A x B)	29.45	1	29.45	1.62	NS
MR	Types of Players (A)	7115.07	1	7115.07	225.92	0.01
	Gender (B)	0.27	1	0.27	0.00	NS
	(A x B)	1.47	1	1.47	0.04	NS

Key: PS: Psychological Skills; AM: Achievement Motivation; GS: Goal Setting; AC: Anxiety Control; MC: Maintaining Confidence; CON: Concentration; MR: Mental Rehearsal

Table 4. Summary of two-way ANOVA of aggression among sports majors

Variables	Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Aggression	Types of Players (A)	3794.96	1	3794.96	71.54	0.01
	Gender (B)	165.76	1	165.76	3.12	NS
	(A x B)	30.08	1	30.08	0.56	NS
Go-Ahead	Types of Players (A)	887.52	1	887.52	31.77	0.01
	Gender (B)	16.33	1	16.33	0.58	NS
	(A x B)	9.72	1	9.72	0.34	NS
Foul Play	Types of Players (A)	27.00	1	27.00	2.36	NS
	Gender (B)	56.33	1	56.33	4.94	0.05
	(A x B)	21.33	1	21.33	1.87	NS
Assertiveness	Types of Players (A)	708.40	1	708.40	35.57	0.01
	Gender (B)	1.76	1	1.76	0.08	NS
	(A x B)	5.07	1	5.07	0.25	NS

dimensions. Comparing these findings with the descriptive statistics in Table 1, the higher mean scores for University of Delhi students across all aggression dimensions align with the significant effects of Types of Players, while the significant influence of Gender on Foul Play corresponds with the higher mean scores for male students, suggesting that player type and gender play a role in shaping aggressive behaviors among sports majors. The non-significant interaction effects

indicate that the influence of Types of Players and Gender on aggression dimensions is independent of each other.

Table 5. Pearson Correlation Matrix of Psychological Skills and Aggression among Sports Majors

Variables	Psychological Skills	Aggression
Psychological Skills	1	.284**
Aggression	.284**	1

Note: **Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed).

There is a positive correlation ($r = .284$, $p = 0.01$) between psychological skills and aggression among University of Baghdad and University of Delhi sports majors ($n = 300$), which is significant at the 0.01 level (2-tailed). This indicates a weak positive relationship between the two variables, suggesting that as psychological skills improve, there is a slight tendency for aggression levels to increase as well. In other words, higher psychological skills are associated with a modest increase in aggression among sports majors.

Discussion

The current study explores the gender differences in psychological skills and aggression among university athletes from Delhi and Baghdad, offering a cross-cultural perspective on these constructs. The results from Tables 1 and 2 present clear evidence of significant variations in psychological skills and aggression across gender and university, with University of Delhi students scoring notably higher across all psychological skills and aggression dimensions. The disparity in psychological skills between Delhi and Baghdad athletes can be attributed to differing training environments, cultural influences, and sports development programs, which may explain why male and female athletes from University of Delhi consistently outperform their counterparts from University of Baghdad. These findings align with previous research that highlights the importance of cultural context in the development of psychological skills in athletes (Si et al., 2011; Champ et al., 2020).

The findings of this study reveal that female athletes in both Delhi and Baghdad universities scored higher in psychological skills, particularly in anxiety control and concentration. This contradicts much of the existing literature that typically reports superior psychological skills in male athletes (Shrivastava, 2013; Parnabas, 2015; Karamousalidis et al., 2006). One explanation for this discrepancy may lie in cultural and societal factors specific to these regions, where female athletes face additional barriers and pressures in sports, potentially fostering stronger psychological resilience (Forsyth et al., 2019). Additionally, socialization patterns may encourage emotional regulation in women, leading to more effective coping strategies in managing anxiety and maintaining focus (Monteiro et al., 2014). These results suggest that gender differences in psychological skills may be influenced by context, highlighting the need for further research to explore how cultural and environmental factors shape these skills across different populations (Matsumoto & Juang, 1996; Bouchard Jr & McGue, 2003)

On the other hand, male athletes demonstrated higher aggression levels, with Delhi University males exhibiting particularly elevated scores in assertiveness and Go-Ahead behaviors. These gender differences in aggression, particularly in the Go-Ahead dimension, support the notion that male athletes are more inclined toward overt competitive behaviors, which are often encouraged in male-dominated sports environments (Rahimizadeh et al., 2011; Ullah & Iftikhar, 2021; Nixon, 1997).

Furthermore, the significant effect of "Types of Players" on psychological skills and aggression, as indicated by the ANOVA results, reinforces the idea that different levels of competition and sports specialization have a profound impact on both mental and behavioral outcomes. The higher scores in psychological skills among Delhi athletes could be linked to the university's emphasis on competitive sports and psychological conditioning, which are crucial for high-level athletic performance (Fletcher & Wagstaff, 2009). This is further supported by the positive but weak correlation ($r = 0.284$, $p < 0.01$) between psychological skills and aggression, suggesting that athletes who possess higher psychological skills tend to display slightly higher levels of aggression, possibly due to their heightened competitiveness and mental focus.

The non-significant interaction between Types of Players and Gender for aggression dimensions implies that these factors operate independently in influencing aggressive behavior. This finding suggests that while both player type and gender affect aggression, they do not interact in a way that amplifies or diminishes each other's impact. This independence may reflect broader societal patterns, where gender and sports participation are influenced by different cultural expectations and experiences (Lau et al., 2007; Coakley & White, 1992). The weaker influence of gender on some aggression sub-scores, such as Foul Play, highlights the complexity of these behaviors, which may not be as strongly tied to gender norms as assertiveness or goal-directed aggression.

Conclusions

In summary, this study highlights significant cross-cultural and gender differences in psychological skills and aggression among university athletes. The findings underscore the need for tailored psychological training programs that consider both cultural and gender-specific factors to enhance athlete mental resilience and behavior management in competitive sports. Future research could benefit from examining these variables in other cultural contexts to generalize the findings further, and to investigate how cultural shifts in gender roles may influence the psychological development of athletes.

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Conflicts of Interest

We declare that there are no conflicts of interest.

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З'ясування гендерних відмінностей щодо психологічних навичок та агресії серед університетських спортсменів: Крос-культурне порівняння показників між представниками Делі та Багдада

Ахмед Джаббар Абійра[1ABCD], Сандеп Тіварі[1ABCD], Сандья Тіварі[1ABCD], Мір Ахсан Аль Хак[1ABCD]

[1]Делійський університет

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.

Історія питання. Психологічні навички та агресія є визначальними чинниками спортивної результативності, на які впливають як гендерний, так і культурний контексти. На формування цих факторів позначаються індивідуальні відмінності та культурні впливи, і вони мають ключове значення для розвитку та використання вказаних навичок спортсменами у спорті.

Мета дослідження. Метою цього дослідження було визначити відмінності у психологічних навичках та рівнях агресії залежно від статі та ВНЗ, надаючи розуміння психологічних профілів спортсменів у межах різних культурних контекстів.

Матеріали та методи. У дослідженні взяли участь 300 спортсменів віком від 18 до 30 років, що навчалися у Делійському (Індія) та Багдадському університетах (Ірак). Кожен університет представив 150 спортсменів, порівну розподілених за статевою приналежністю (75 чоловіків і 75 жінок). Учасників було відібрано за допомогою методів неімовірнісної квотної та цілеспрямованої вибірок. Для оцінки психологічних навичок було застосовано опитувальник психологічних навичок у спорті ("Psychological Skills Inventory for Sports", PSIS), а рівень агресії визначали за допомогою опитувальника спортивної агресії ("Sports Aggression Questionnaire"). Збір даних проводився в контрольованому середовищі під наглядом підготовлених науковців. Методи статистичного аналізу включали двофакторний дисперсійний аналіз (ANOVA) та коефіцієнти кореляції Пірсона із використанням програмного забезпечення SPSS.

Результати. Спостерігалися значні відмінності у психологічних навичках та рівнях агресії між досліджуваними університетами та гендерними групами. Згідно з отриманими даними, спортсмени Делійського університету продемонстрували більш розвинені психологічні навички (PS: 154,83 ± 18,50) порівняно зі спортсменами Багдадського університету (PS: 109,83 ± 26,05). Крім того, спортсмени чоловічої статі з Делі мали вищий показник агресії (44,41 ± 10,35), ніж їхні

багдадські колеги (37,93 ± 4,20). За результатами двофакторного дисперсійного аналізу встановлено, що тип гравця суттєво впливає на психологічні навички (F = 300,47, p = 0,01) та рівень агресії (F = 71,54, p = 0,01). Статева приналежність також суттєво вплинула на контроль тривожності (F = 8,64, p = 0,01) та нечесну гру (F = 4,94, p = 0,05). Визначено слабку позитивну кореляцію (r = 0,284, p = 0,01) між психологічними навичками та рівнем агресії, що свідчить про незначну тенденцію до посилення психологічних навичок, що відповідає вищим рівням агресії.

Висновки. Представлені результати підкреслюють важливість врахування гендерного та університетського контекстів щодо оцінки психологічних навичок та рівня агресії у спортсменів. Отримані під час дослідження висновки можуть слугувати основою для розробки цільових програм підготовки та стратегій підтримки, спрямованих на покращення результативності та благополуччя спортсменів.

Ключові слова: психологічний навик, агресія, гендерні відмінності, університетські спортсмени, крос-культура.

Information about the authors:

Abiyra, Ahmed Jabbar: ahmediraqindia@gmail.com; https://orcid.org/0009-0004-4816-6525; Department of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Tiwari, Sandeep: sandeeptiwari1964@yahoo.co.in; https://orcid.org/0009-0009-0964-800X; Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Tiwari, Sandhya: tiwarisandhya22@yahoo.co.in; https://orcid.org/0009-0005-1709-4765; Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Haq, Mir Ahsan Ul: ehsaanmeer1@gmail.com; https://orcid.org/0009-0006-6282-3688; Department of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

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Original Scientific Article

Considering the Effects of Upper Body, Lower Body, and Their Combination on Post-Activation Performance Enhancement of Bowling Velocity Among Amateur Cricket Players

Bhargav Sarmah[1ABCD], Nishanta Bordoloi[2AD], Pushpendra Narvariya[3AD] and Rohit Kumar Thapa[4ACD]

[1]Rashtriya Raksha University
[2]National Cricket Academy, India
[3]Amity University
[4]Symbiosis International (Deemed University)

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

Corresponding Author: Rohit Kumar Thapa, e-mail: rohit.thapa@ssss.edu.in
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Abstract

Objectives. This study aimed to investigate the effects of post-activation performance enhancement on bowling velocity among amateur cricket players using multiple interventions as conditioning activities focusing on the upper body, lower body, and a combination of both.

Materials and methods. Eight amateur cricket bowlers were recruited for the study and, in a randomized crossover manner, allocated to conditioning activities aimed at the upper body (i.e., 10 pull-ups + 6 wall ball slams), lower body (i.e., 10 air squats + 6 broad jumps), or both (5 pull-ups + 3 wall ball slams combined with 5 air squats + 3 broad jumps). The bowling velocity was measured at baseline and after one minute and four minutes of completing the intervention.

Results. The findings indicate no significant improvement ($p = 0.939$) in ball velocity compared to the control condition after the three experimental conditions. However, post-hoc results showed a substantial decrease in bowling velocity after one minute.

Conclusions. In conclusion, conditioning activities using pull-ups and wall ball slams for the upper body, air squats, and broad jumps for the lower body, or their combination, do not induce post-activation performance enhancement during cricket bowling.

Keywords: post-activation potentiation, speed, athletic performance, plyometric exercise.

Introduction

Cricket is a sport played between two teams, with one team bowling and the other team batting (Bartlett, 2003; Noakes & Durandt, 2000). The batting team aims to score as many runs as possible, whilst the bowling team aims to minimize the runs scored. During the match, one player from the bowling team delivers the ball to the batting team at varying speeds and/or spin (i.e., fast bowlers and spin bowlers). The fast bowlers aim to deliver the ball to the batsman at the highest possible velocity. Thus, it is of paramount importance for a fast bowler to achieve the maximal velocity of the ball delivery (Noakes & Durandt, 2000).

The physical performance of athletes can be increased via different training strategies on a long-term or short-term basis. One such strategy to induce acute improvement in physical performance is post-activation performance enhancement (PAPE) (Blazevich & Babault, 2019). The PAPE is characterized by a short-term enhancement in performance (e.g., strength) subsequent to a conditioning exercise. Mechanistically, PAPE is suggested to be associated with post-activation potentiation occurring approximately 28 seconds after the conditioning exercise (Blazevich & Babault, 2019; Hodgson et al., 2005). This phenomenon involves heightened phosphorylation of myosin regulatory light chains, increased recruit-

ment of fast-twitch motor units, and various factors contributing to its duration, including elevated muscle temperature, intramuscular fluid accumulation (e.g., muscle blood flow and water), decreased muscle pH, and heightened neural drive (i.e., increased muscle activation) (Blazevich & Babault, 2019). However, for the optimization of PAPE's efficacy, conditioning exercises should be tailored to target specific aspects of performance improvement. Additionally, since both performance enhancement and fatigue can co-exist following PAPE-inducing conditioning exercises, careful consideration of the timing, particularly the rest interval between the application of PAPE-inducing stimuli and the subsequent competitive or performance activity, is crucial to prevent fatigue from overshadowing the potentiation effects (Chen et al., 2024).

Positive effects of PAPE using various exercises as conditioning activities have been observed across various sports activities and skills (Esformes et al., 2011; Gossen & Sale, 2000; Vargas-Molina et al., 2021). In addition, in a recent meta-analysis the authors reported ballistic jump exercises induced PAPE during jumping and sprinting (Ulloa-Sánchez et al., 2024). Moreover, recently, researchers have also studied the effects of different conditioning activities in inducing PAPE during sports-specific performance (e.g., using a combination of ballistic jumps to improve judo-specific performance) (Baruah et al., 2024). Furthermore, using ballistic throws as a conditioning activity has also been reported to induce PAPE for upper-body throwing performance after 3 minutes of recovery (Finlay et al., 2022). However, there are no researchers who studied the effects of conditioning activities on the PAPE of bowling velocity of cricket bowlers. Specifically, whether PAPE can be achieved using the upper body, lower body, or their combination to improve the ball velocity during cricket bowling among pace bowlers has not yet been studied. Therefore, this study aimed at comparing the effects of upper-body, lower-body, or their combination in improving the ball velocity during cricket bowling among pace bowlers.

Materials and Methods

Participants

Eleven collegiate-level male cricket bowlers were initially recruited for the study. However, only 8 participants (aged: 19.3 ± 1.2 yrs., height: 170.8 ± 3.0 cm; body mass: 67.1 ±3 .5 kgs) completed the study. All the participants had a minimum of five years of training experience in cricket. The participants were actively practicing the sport during the data collection. The inclusion criteria required participants to (1) be male, (2) have a minimum of one year of resistance training experience, (3) be adult, and (4) be injury-free with no major injuries in the past 6 months. The participants were explained the details of the study and the risks associated with the study. Thereafter, the participants signed informed consent forms. The study was approved by the Internal Review Board of the School of Physical Education and Sports, Rashtriya Rakhsa University (approval number: RRU/SPES/EEF/FMR/139, dated 21/12/2023), and conducted according to principles in the updated declaration of Helsinki.

Experimental Design

The study utilized a randomized cross-over design. Participants completed two familiarization sessions to avoid the learning effects and four actual experimental sessions to examine the effects of the conditioning activities on ball velocity during medium pace bowling. During the familiarization sessions, the anthropometric characteristics were recorded. In the experimental sessions, the baseline data were recorded which was followed by the warm-up. The control group performed the warm-up, whereas the experimental group replaced some parts of the warm-up with the conditioning exercises.

Conditioning Protocols

The conditioning protocols used in the study are presented in Table 1. The conditioning activities were performed based on contrast training format, i.e., exercise 1 followed by exercise 2, in a set-by-set fashion (Thapa et al., 2021). A total of 3 sets were performed. For combined, the upper body exercise sets were completed first followed by lower body exercise sets.

Table 1. Conditioning protocol

	Exercise 1	Repetitions	Exercise 2	Repetitions
Upper-body	Pull-ups	10	Wall ball slams	6
Lower-body	Air Squats	10	Broad jumps	6
Combined	Pull-ups	5	Wall ball slams	3
	Air squats	5	Broad jumps	3

Note: Three sets were performed

Data Collection

A reliable (Makar et al., 2024) radar gun (Bushnell Velocity Gun Model# 101911, Overland Park, Kansas 66214) having a tracking history with a Ball of 16-177 km/hr at 27 meters with accuracy: ± 1.6 km/hr was used to quantify the pace bowling velocity in cricket: baseline, one minute after the conditioning activities, and four minutes after the conditioning activities. The height of the radar gun was kept consistent across the testing sessions and placed at the bowler's end. As the first point of reference, the baseline measurement reflected the bowler's natural pace before any external interventions were applied. In order to assess any PAPE effects of the interventions on bowling velocity, measurements were taken at one and four minutes after the intervention.

Statistical Analysis

Data are presented as means and standard deviations. The normality of the data was verified using the Shapiro-Wilk normality test. A four (conditions: control, upper body conditioning, lower body conditioning, combined conditioning) by three (time: baseline, one-minute, four-minute) repeated measures ANOVA was used to identify the effect of conditioning activities on bowling velocity. Post-hoc tests were conducted using t-tests with Bonferroni corrections. The statistical significance was set at p-values of ≤ 0.05.

Results

The means and standard deviations at baseline, post-one-minute, and post-four-minute are presented in Table 2. No significant condition × time was observed ($p = 0.939$).

Table 2. Mean and standard deviation of ball velocity

Variables	Control	Upper body	Lower body	Combined
	Mean (standard deviation)			
Baseline (km/hr)	101.8 (3.4)	101.8 (3.4)	101.8 (3.4)	101.8 (3.4)
Post-one-min (km/hr)	100.3 (4.5)	98.3 (2.4)*	98.9 (2.7)*	98.4 (2.8)*
Post-four-min (km/hr)	102.8 (5.6)	101.1 (4.1)	101.3 (4.1)	101.8 (5.2)
P value (condition × time)	0.939			

Note: * significant difference with baseline

However, post-hoc analyses showed a significant decrease in the ball velocity post one minute after all three conditioning activities.

Discussion

The study aimed to investigate the PAPE effects of conditioning activity using upper body exercise, lower body exercise or their combination on the ball velocity of amateur-level medium-pace bowlers in cricket. The findings suggest a significant decrease in ball velocity after one minute but no difference after four minutes of performing the conditioning activities.

The significant decrease in ball velocity after one minute of conditioning activities may be due to the fatigue associated with the conditioning activities (Hodgson et al., 2005). The balance between the PAPE and fatigue is important in order to observe the phosphorylation of myosin regulatory light chains and recruit higher-order motor units (Blazevich & Babault, 2019). Therefore, it is plausible that a one-minute recovery was insufficient in minimizing the effect of fatigue on the ball velocity. However, although previous studies have suggested that PAPE can be achieved at a shorter duration with ballistic conditioning activities (Seitz & Haff, 2016; Thapa et al., 2020), there are various moderating factors associated with PAPE (e.g., relative strength, training experience) (Blazevich & Babault, 2019). Of note, the participants involved in the current study were amateur-level cricketers, which may have reduced the effect of the conditioning activities since the strength level of the participants moderates the PAPE effects (Blazevich & Babault, 2019; Seitz & Haff, 2016). However, no previous study has researched the effects of conditioning activities on cricket bowling velocity; hence, a direct comparison is not possible. Although not in cricket, these findings align with a previous study conducted on baseball athlete's pitching velocity (Carrier, 2019). Carrier (2019) reported that conditioning activities using ballistic medicine ball throws did not significantly affect baseball pitching velocity one minute after the application of the conditioning activity in collegiate-level baseball athletes.

Furthermore, after four minutes of the conditioning activities, the ball velocity returned to a similar level as the baseline values. It may be possible that the fatigue due to the conditioning activities started diminishing with a longer recovery (Blazevich & Babault, 2019). Of note, in the current study, the authors did not collect data beyond four minutes recovery duration, and in several PAPE studies, it has been suggested that an optimal window for the PAPE effect after a heavy-load conditioning activity is a beyond four-minute duration (e.g., 8-12 minutes) (Esformes et al., 2011; Finlay et al., 2022). Therefore, future research should study the effects of various ballistic conditioning activities (e.g., using elastic bands) on enhancing bowling velocity beyond a four-minute duration (e.g., eight minutes) in cricketers from various competitive level.

There are a few limitations in the study that should be acknowledged. Firstly, the authors could recruit only 8 participants for the study. Due to the study's demand to recruit only amateur medium-pace bowlers, the authors could reach this current sample size threshold. Secondly, only male bowlers were included in the study. Therefore, the results of this study should not be extrapolated to female bowlers. Thirdly, based on previous literature on using ballistic conditioning activities to induce PAPE (Seitz & Haff, 2016), the recovery duration chosen for PAPE was 1-minute and 4-minute time-point. However, the current findings necessitate the need for studies with longer recovery duration (e.g., 8 minutes). Furthermore, previous studies have used heavy-load resistance exercises to evoke the PAPE effect across different athletic movements (e.g., jumps, sprints). Therefore, future research should also use high-intensity resistance exercises to study the effects on PAPE on different physical aspects of a cricket bowler.

Conclusion

In conclusion, no PAPE effects were observed using the upper body, lower body, or their combination in ball velocity among amateur male medium-pace bowlers. Of note, a negative effect on bowling performance was observed after 1 minute of recovery, suggesting a complex relationship between potentiation and fatigue.

Conflicts of interest

We declare that there are no conflicts of interest.

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Розгляд впливу системи силових вправ, призначених для розвитку верхнього, нижнього відділів тіла та їхнього поєднання на постактиваційне підвищення результативності показників швидкості виконання боулінгу серед гравців-аматорів у крикет

Бхаргав Сарма[1ABCD], Нішанта Бордолой[2AD], Пушпендра Нарварія[3AD], Рохіт Кумар Тапа[4ACD]

[1]Університет Раштрія Ракша
[2]Національна академія крикету (Індія)
[3]Університет Аміті
[4]Міжнародний університет Симбіозис

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

Реферат. Стаття: 5 с., 2 табл., 21 джерело.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу постактиваційного підвищення результативності на показники швидкості виконання боулінгу (дії, спрямовані на просування м'яча до воріт) серед гравців-аматорів у крикет, використовуючи кілька інтервенцій у вигляді кондиціонуючих вправ, спрямованих на розвиток верхнього та нижнього відділів тіла, а також поєднання зазначених типів тренувань.

Матеріали та методи. Для проведення дослідження було відібрано вісім гравців-аматорів у крикет, яких розподілили за методом рандомізованого перехресного типу з метою виконання кондиціонуючих вправ, спрямованих на розвиток верхнього відділу тіла (10 підтягувань + 6 ударів м'ячем об стінку), нижнього відділу тіла (10 повітряних присідань — класичні присідання без використання додаткового обтяження (власна вага) + 6 стрибків у довжину з місця) або поєднання

обох видів тренувань (5 підтягувань + 3 удари м'ячем об стінку в комплексі із 5 повітряними присіданнями + 3 стрибками у довжину з місця). Вимірювання швидкості виконання боулінгу проводилося на початковому етапі дослідження, а також через одну хвилину та чотири хвилини після завершення інтервенції.

Результати. Отримані дані свідчать про відсутність значного покращення (p = 0,939) швидкості польоту м'яча порівняно із контрольним станом після виконання трьох експериментальних умов. Однак post-hoc результати показали суттєве зменшення швидкості виконання боулінгу через одну хвилину.

Висновки. Таким чином, кондиціонуючі вправи, що включають в себе виконання підтягувань і удари м'ячем об стінку для верхнього відділу тіла, а також повітряні присідання та стрибки у довжину з місця для нижнього відділу тіла, або комбінація вказаних видів тренувань, не сприяють постактиваційному підвищенню показників результативності під час виконання боулінгу в крикеті.

Ключові слова: постактиваційне потенціювання, швидкість, спортивна результативність, пліометричні вправи.

Information about the authors:

Sarmah, Bhargav: bhargav.sarmah@rru.ac.in; https://orcid.org/0009-0009-6576-4208; School of Physical Education and Sport, Rashtriya Raksha University, At. Lavad, Ta. Dehgam, Gandhinagar, 380305, India.

Bordoloi, Nishanta: djnishant@gmail.com; National Cricket Academy (India), Mahatma Gandhi Rd, near Cubbon Road, Shivaji Nagar, Bengaluru, Karnataka 560001, India.

Narvariya, Pushpendra: pnarvariya@amity.edu; https://orcid.org/0000-0002-7045-3465; Amity School of Physical Education and Sports Sciences, Amity University, opposite Airport, Maharajpura, Gwalior, Madhya Pradesh 474005, India.

Thapa, Rohit Kumar: rohit.thapa@ssss.edu.in; https://orcid.org/0000-0002-1258-9065; Symbiosis School of Sport Sciences, Symbiosis International (Deemed University), Lavale, Mulshi, Pune, Maharashtra 412115, India.

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Original Scientific Article

Determining the Efficacy of Providing Ice Compression for Fitness Enhancement After Speed Endurance Exercise on Reducing Heart Rate, IL-6, and Fatigue Index in Football Athletes

Muhammad Kharis Fajar[1ABDE], Agus Hariyanto[1ABD], Endang Sri Wahjuni[1ABD], Dwi Cahyo Kartiko[1BD], Gigih Siantoro[1BD], Yanyong Phanpheng[2BD], I Dewa Made Aryananda Wijaya Kusuma[1BD], Bayu Agung Pramono[1BD], Afif Rusdiawan[1BD] and Adi Pranoto[1BCD]

[1]Universitas Negeri Surabaya
[2]Loei Rajabhat University

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

Corresponding Author: Muhammad Kharis Fajar, e-mail: muhammadfajar@unesa.ac.id
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Abstract

Objectives. This study aimed to investigate the effects of Ice Compression For Fitness (ICEFIT) on reducing heart rate, Interleukin-6 (IL-6) levels, and fatigue index in soccer athletes after performing speed endurance training.

Materials and methods. A total of 34 male students from the Football Coaching Department at the State University of Surabaya (Indonesia), aged 18-20 years, with a normal BMI, at least 10 years of football training experience, and no injuries in the past 6 months, were selected as research subjects and were given ICEFIT treatment for 4 weeks. Data collection was conducted by measuring heart rate, IL-6 levels, and fatigue index at both the pre- and post-intervention stages. Data analysis techniques included using the parametric paired sample t-test and independent sample t-test, with a significance level of 5 %.

Results. The results showed that ICEFIT significantly reduced heart rate, IL-6 levels, and fatigue index in soccer athletes after speed endurance training ($p \leq 0.05$). Furthermore, marked reductions in heart rate, IL-6 levels and fatigue index were observed between the groups ($p \leq 0.05$).

Conclusions. These findings demonstrate that ICEFIT is effective in reducing heart rate, IL-6 levels, and fatigue index in soccer athletes after speed endurance training.

Keywords: ICEFIT, proinflammatory cytokine, soccer athletes, speed endurance training.

Introduction

Football, known as the most popular sport worldwide, is a large ball game played by two teams, each consisting of 11 players, led by a referee and two assistant referees, with one substitute or backup referee (Lepschy et al., 2018; Irfan et al., 2020). The official rules stipulate that football is played for a total of 90 minutes, divided into two halves of 45 minutes each, with a 15-minute halftime break in between (Dolci et al., 2020). Football is a sport that utilizes both aerobic and anaerobic energy systems, although the predominant energy system used is anaerobic (Evangelos et al., 2016). The anaerobic system is required during high-intensity sprints performed in technical and tactical tasks, such as defense and attack, while the aerobic system ensures continuity in high-intensity anaerobic efforts and accelerates recovery processes (Stojmenović & Stojmenović, 2023).

Throughout a half, football players are constantly moving, with or without the ball. Players moving without the ball perform tasks involving jogging, running, acceleration, sprinting, maximal sprints, high-intensity acceleration, and deceleration (Leontijević et al., 2019). Players controlling or attacking with the ball exhibit skills such as passing, first touch, controlling, dribbling, heading, and shooting (Kusuma et al., 2023). The pace of football games has been

steadily increasing, making it one of the highest-intensity sports today (Rivilla-García et al., 2019). In fact, the intensity of football matches has risen significantly in top leagues such as the English Premier League (EPL) (Barnes et al., 2014).

As the intensity and duration of football games increase, training programs that emphasize the anaerobic energy system are required, one of which is speed endurance training. Speed endurance training is part of high-intensity interval training (HIIT), characterized by sustained periods of intense activity interspersed with short active recovery periods (Ramírez et al., 2017). Despite being demanding for athletes, research has found that speed endurance training positively impacts both anaerobic and aerobic capacities (Ramírez et al., 2017).

However, the significant effects of anaerobic training can pose negative risks to the body if not addressed properly. High-intensity anaerobic training will linearly increase heart rate (D'Unienville et al., 2022) and, if prolonged, can lead to fatigue (Güler et al., 2020). Fatigue results from lactic acid accumulation, which reduces muscle contraction ability and athletic performance (Sari et al., 2019; Zubaida et al., 2023). Selain Additionally, lactic acid production in working muscles correlates with the release of Interleukin-6 (IL-6) (Robson-Ansley et al., 2004). Research indicates that high-intensity exercise in humans and intramuscular lactate injections in rats closely correlate with systemic IL-6 release. This supports the connection between exercise intensity, lactate production, and IL-6 release during strenuous activity (Nash et al., 2023). Dengan The relationship between lactic acid production and IL-6 release helps explain why IL-6 secretion increases during high-intensity exercise and glycogen depletion (Smith, 2000).

Recovery is critical for football players. Recovery refers to the process of restoring the body's metabolic functions to normal after strenuous activity, enabling the individual to be ready for future tasks (Fahmi & Ashadi, 2019). Recovery is critical for football players. Recovery refers to the process of restoring the body's metabolic functions to normal after strenuous activity, enabling the individual to be ready for future tasks (Carling et al., 2018; Handoko & Bagaskoro, 2021; Marqués-Jiménez et al., 2017).

Given the importance of recovery in football, interventions that can accelerate the recovery process are essential, one of which is cold water or ice treatment. Research has shown that cold water immersion during halftime significantly slows muscle fatigue and reduces lactic acid levels in football players (Panyakham & Pariwat, 2022). A study by Fakhro et al. (2022) also found that cold water immersion is highly effective in improving recovery from exercise-induced muscle damage (EIMD). Additionally, cold water immersion has been shown to reduce muscle damage markers in the blood after simulated match training in football players (Roonkiani et al., 2020).

Based on the explanation above, football predominantly relies on anaerobic energy systems, requiring training programs that improve anaerobic capacity. As football is a sport that demands continuous high-intensity activity over long periods, players are prone to fatigue, characterized by increased heart rate, elevated IL-6 levels, and a high fatigue index. These conditions hinder football players' performance, making recovery crucial to preparing them for subsequent activities. If left unaddressed, athletes may not be able to perform optimally. Therefore, a modality that accelerates the recovery process in soccer athletes is necessary. This study will use an intervention called Ice Compression For Fitness (ICEFIT). This ICEFIT intervention is designed to help soccer athletes recover their heart rate, IL-6 levels, and fatigue index after speed endurance training.

Materials and Methods

Study Design

This study employed a true-experimental method with a randomized control group pretest-posttest design. A total of 34 male students from the Football Coaching Department at Universitas Negeri Surabaya, aged 18-20 years, with normal BMI, at least 10 years of football training experience, and no injuries in the last 6 months, were selected as research subjects. Informed consent was obtained before the initial data collection from all subjects. All procedures applied in this study were approved by the Health Research Ethics Committee of the Faculty of Medicine, Ciputra University [No: 107/EC/KEPK-FKUC/III/2024].

Programs of Speed Endurance Training for Soccer

The speed endurance training applied in this study involved repeated high-intensity sprints aimed at achieving anaerobic conditions, combined with technical drills for passing and dribbling. The speed endurance training was conducted for 4 weeks with three sessions per week. During weeks 1 and 2, the training consisted of 8 repetitions, with a total sprint distance of 80 meters and a 1:2 work-to-rest ratio (estimated workout time of 96 seconds and rest interval of 192 seconds per repetition). In weeks 3 and 4, the training also included 8 repetitions, with a total sprint distance of 80 meters, but the work-to-rest ratio was changed to 1:1 (estimated workout time of 96 seconds and rest interval of 96 seconds per repetition).

Ice Compression For Fitness (ICEFIT) Procedure

The ICEFIT procedure was applied during the training intervals (3 minutes in weeks 1 and 2; 1.5 minutes in weeks 3 and 4). Ice was applied in the form of an ice pack at a temperature of 15 °C and placed on the back of the subject's neck. The ice compression was administered 7 times per training session over 12 training sessions.

Data Collection

Data collection was conducted by measuring heart rate using Polar (Polar H10 Sensor, Inc., USA) (Pranoto et al., 2023a). The fatigue index was measured using the Running-Based Anaerobic Sprint Test (RAST), in watts/sec, and calculated using the formula: Maximum power – minimum power ÷ total time for the 6 sprints. Meanwhile, IL-6 levels were analyzed using commercial ELISA Kits (Cat. No.: E-EL-H6156; Human IL-6 ELISA Kit; Elabscience Biotechnology Inc., Houston, TX 77079, USA) (Pranoto et al., 2023b).

Statistical Analysis

Normality tests were conducted using the Shapiro–Wilk test, followed by parametric paired sample t-tests to assess differences within each group. Independent sample t-tests

were applied to evaluate differences between groups. Effect size was evaluated using Cohen's d. Data were considered significantly different between groups if $p \leq 0.05$.

Results

The analysis of the general characteristics of the study subjects showed no significant differences between the groups, as presented in Table 1. The results of the analysis of heart rate, IL-6 levels, and fatigue index before and after the ICEFIT intervention are shown in Figures 1-3. The analysis of the differences in heart rate, IL-6 levels, and fatigue index between the control group (CON) and the ICEFIT group is presented in Table 2.

Table 1. General characteristics of study subjects

Parameters	CON (n = 17)	ICEFIT (n = 17)	p-value
Age (years)	21.47 ± 0.79	21.06 ± 0.89	0.168
Height (m)	1.68 ± 0.07	1.71 ± 0.03	0.162
Weight (kg)	65.59 ± 7.79	67.18 ± 6.12	0.513
Body Mass Index (kg/m2)	23.33 ± 1.61	22.93 ± 1.75	0.493
Training Experience (years)	10.12 ± 2.18	10.29 ± 2.52	0.828

Note: CON: Control group; ICEFIT: Ice compression enhancement for fitness group

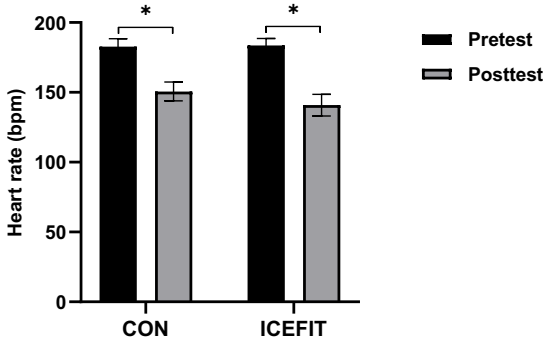

Fig. 1. Average heart rate in each group. Description: (*) Indicates a significant difference from the pretest ($p \leq 0.05$)

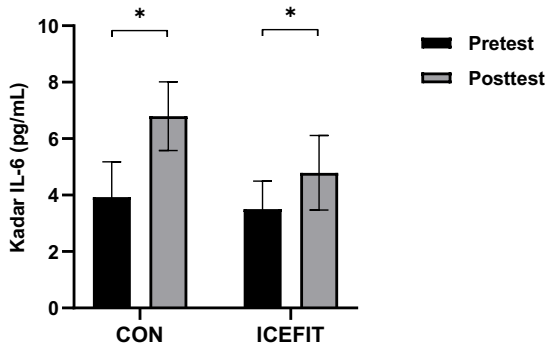

Fig. 2. Average IL-6 levels in each group. Description: (*) Indicates a significant difference from the pretest ($p \leq 0.05$)

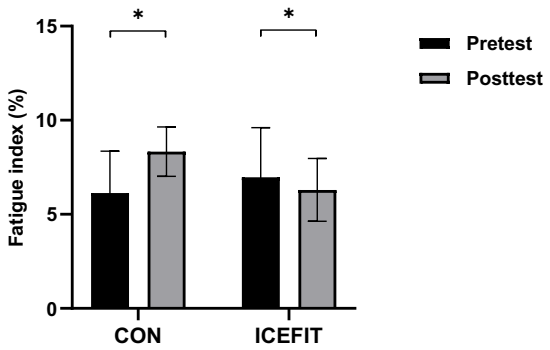

Fig. 3. Average fatigue index in each group. Description: (*) Indicates a significant difference from the pretest ($p \leq 0.05$

Discussion

The main findings of this study indicate that ICEFIT intervention significantly modulates post-exercise inflammatory response, heart rate recovery, and fatigue index in athletes after high-intensity speed endurance training. Specifically, athletes who received the ICEFIT treatment experienced lower increases in IL-6 levels, faster heart rate recovery, and more controlled fatigue compared to the control group.

The reduction in IL-6 levels aligns with previous research showing that cryotherapy and compression can mitigate

Table 2. Differences in heart rate, IL-6 levels, and fatigue index between groups

Parameters	CON (n=17)	ICEFIT (n=17)	Effect size	p-value
Pre-Heart rate (bpm)	182.67 ± 5.69	183.51 ± 5.03	-	0.652
Post-Heart rate (bpm)	150.63 ± 6.75	140.89 ± 7.74*	1.341	0.000
Δ-Heart rate (bpm)	-32.04 ± 8.81	-42.62 ± 8.12*	1.249	0.001
Pre-IL-6 (pg/mL)	3.93 ± 1.25	3.51 ± 0.99	-	0.279
Post-IL-6 (pg/mL)	6.79 ± 1.22	4.79 ± 1.32*	1.574	0.000
Δ-IL-6 (pg/mL)	2.86 ± 1.99	1.28 ± 0.86*	1.031	0.006
Pre-Fatigue index (%)	6.14 ± 2.23	6.97 ± 2.64	-	0.328
Post-Fatigue index (%)	8.33 ± 1.31	6.29 ± 1.67*	1.359	0.000
Δ-Fatigue index (%)	2.19 ± 2.83	-0.67 ± 2.36*	1.098	0.003

Description: (*) Significant at CON ($p \leq 0.05$). (-) No observed effect size. Effect size was evaluated using Cohen's d. The p-value was applied using independent sample t-tests

inflammatory responses (Sánchez-Ureña et al., 2018; Minett & Costello, 2015). Inflammation is a natural response to intense physical activity and is often accompanied by the release of pro-inflammatory cytokines such as IL-6 (Fujii & Shibata, 2023). However, the role of cryotherapy in controlling systemic inflammation remains debated (Kusmierczyk et al., 2024). While some studies suggest that cryotherapy reduces muscle soreness and local inflammation, its effects on systemic markers like IL-6 are inconsistent (White & Wells, 2013; Elvianasti et al., 2023). The reduction in IL-6 observed in this study may be attributed to the specific combination of cold exposure and compression provided by ICEFIT, which enhances lymphatic drainage and reduces metabolic waste, thereby limiting muscle damage and inflammation following high-intensity exercise.

Regarding heart rate recovery, our findings are consistent with those of Roberts et al. (2015), who found that cold water immersion after resistance exercise reduced cardiac output and stroke volume due to peripheral vasoconstriction. This vasoconstriction helps preserve core body temperature by diverting blood flow from the periphery, a process that may also reduce cardiovascular strain on the heart post-exercise (Moore et al., 2022). Vaile et al. (2011) demonstrated that various forms of cryotherapy, including cold water immersion, accelerate cardiovascular recovery after high-intensity exercise, supporting our conclusion that ICEFIT facilitates faster heart rate recovery. This is further corroborated by Xiao et al. (2023), who found that cooling interventions like ICEFIT improve heart rate variability and promote faster cardiovascular recovery by reducing overall physiological stress. The faster heart rate recovery in the ICEFIT group may be due to a combination of reduced metabolic activity in cooled muscles and improved circulation efficiency through vasoconstriction and blood flow centralization.

The more controlled fatigue index observed in the ICEFIT group is consistent with studies showing that cold water immersion enhances muscle recovery and delays the onset of fatigue (Machado et al., 2016). Fatigue during high-intensity exercise is often associated with the accumulation of metabolic waste, including lactate, and muscle damage (Güler et al., 2020). By lowering muscle temperature, ICEFIT likely slows enzymatic activity and metabolic processes that contribute to fatigue, while compression facilitates the removal of waste products (Minett & Costello, 2015). However, since fatigue was not completely prevented in the ICEFIT group, this suggests that while ICEFIT helps manage fatigue, it may not be sufficient on its own to fully counteract the neuromuscular and metabolic fatigue associated with repeated high-intensity exercise (Horgan et al., 2023).

The modulation of IL-6 levels suggests that ICEFIT may reduce the inflammatory response triggered by muscle damage and metabolic stress. The cryotherapy element likely reduces the influx of pro-inflammatory cytokines by decreasing blood flow to muscle tissue, while compression enhances the clearance of these inflammatory markers through the lymphatic system (Dalgaard et al., 2020; Singh et al., 2017). Furthermore, lowering muscle temperature may slow enzymatic processes related to inflammation and muscle damage (White & Wells, 2013). However, the statistically insignificant reduction in IL-6 in the ICEFIT group suggests that while beneficial, ICEFIT may need to be combined with other recovery modalities or longer recovery periods to produce a more pronounced effect on systemic inflammation.

The improvement in heart rate recovery may also be linked to the vasoconstriction induced by cold exposure, which redirects blood flow to the body's core, reducing cardiovascular strain post-exercise (Roberts et al., 2015). Compression likely enhances this effect by preventing excessive muscle tissue swelling, allowing for more efficient circulation and faster heart rate recovery. This combination supports the notion that ICEFIT improves cardiovascular recovery by optimizing blood flow and reducing the metabolic load on the heart after intense exercise (Xiao et al., 2023).

The partial control over the fatigue index observed in the ICEFIT group reflects its role in reducing muscle soreness and improving functional recovery. However, fatigue is influenced by a variety of factors, including metabolic, muscular, and neural systems (Wan et al., 2017). While ICEFIT may address some of the metabolic factors contributing to fatigue, such as lactate accumulation, it may not fully mitigate neuromuscular fatigue or psychological stress arising from prolonged high-intensity exercise (Güler et al., 2020; Horgan et al., 2023). This suggests that while ICEFIT provides significant recovery benefits, additional interventions or longer recovery times may be needed to fully alleviate fatigue.

These results suggest that ICEFIT could be a valuable recovery tool for athletes in high-intensity sports such as soccer. Its ability to reduce IL-6 levels and enhance heart rate recovery offers significant benefits for athletes who need to recover quickly between training sessions or competitions. Coaches, sports scientists, and athletic trainers may consider incorporating ICEFIT into broader recovery strategies, especially for sports involving repeated high-intensity efforts. The potential of ICEFIT to enhance recovery could translate into improved athletic performance by allowing faster physiological recovery between training efforts. However, this study has several limitations. First, the relatively small sample size may affect the generalizability of the results. Larger-scale studies are needed to confirm these findings in different athletic populations. Second, although IL-6 was measured as a primary marker of inflammation, adding other markers such as C-reactive protein (CRP) or tumor necrosis factor-alpha (TNF-α) would provide a more comprehensive understanding of ICEFIT's impact on inflammation. This study also did not account for individual variations in cold sensitivity, which could influence the results. Finally, the optimal intensity and duration of the ICEFIT intervention remain unclear, as different temperatures and compression levels may produce varying effects on recovery outcomes.

Future research should focus on larger sample sizes and include a range of inflammatory and recovery markers to better understand the physiological effects of ICEFIT. Longitudinal studies investigating the cumulative effects of ICEFIT over a competitive season would also be valuable, as they could assess its long-term benefits and potential adaptive effects. Additionally, further exploration into the optimal temperature, compression levels, and duration of ICEFIT for different sports and athlete types will help refine its practical application. Comparing ICEFIT to other established recovery modalities, such as active recovery

or massage, could also provide insights into its relative effectiveness.

Overall, this study's findings underscore the potential of ICEFIT as an effective recovery intervention for athletes after high-intensity exercise. The treatment significantly improved heart rate recovery and reduced inflammatory responses, as indicated by IL-6 levels. Furthermore, while ICEFIT helped control fatigue increases, it did not fully prevent it. These findings support the use of ICEFIT in practical settings to enhance athletic recovery, although further research is needed to optimize its use and better understand its effects across different sports and individual responses. Continued investigation into the mechanisms underlying ICEFIT's effects will be essential for developing more targeted and efficient recovery protocols in the future.

Conclusion

Based on the results of this study, ICEFIT was proven to significantly reduce heart rate, Interleukin-6 (IL-6) levels, and fatigue index in soccer athletes after performing speed endurance training. Moreover, there were significant differences between the group receiving ICEFIT and the control group in terms of reductions in these three variables. This demonstrates that ICEFIT is effective in aiding recovery and reducing fatigue following intense exercise in soccer athletes.

Conflict of Interest

The authors declare that they have no competing interests.

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Визначення ефективності застосування льодової компресії з метою покращення стану фізичної підготовленості щодо зниження частоти серцевих скорочень, рівня ІЛ-6 та індексу втоми спортсменів-футболістів після виконання вправ, спрямованих на розвиток швидкісної витривалості

Мухаммад Харіс Фаджар[1ABDE], Агус Харіянто[1ABD], Ендан Шрі Вахджуні[1ABD], Дві Кахйо Картіко[1BD], Гігіх Сіанторо[1BD], Яньон Пханпхен[2BD], І Дева Маде Арянанда Віджая Кусума[1BD], Баю Агун Прамоно[1BD], Афіф Русдьяван[1BD], Аді Праното[1BCD]

[1]Сурабайський державний університет
[2]Лоейський університет Раджабхат

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

Реферат. Стаття: 8 с., 2 табл., 3 рис., 41 джерело.

Мета дослідження. Метою цього дослідження було вивчити вплив льодової компресії для покращення стану фізичної підготовленості (ICEFIT) на зниження частоти серцевих скорочень, рівнів інтерлейкіну-6 (ІЛ-6) та індексу втоми у спортсменів-футболістів після виконання тренувань на розвиток швидкісної витривалості.

Матеріали та методи. Загалом 34 студенти чоловічої статі з факультету підготовки футбольних тренерів Державного університету Сурабаї (Індонезія) віком 18-20 років з нормальним показником індексу маси тіла, щонайменше 10-річним досвідом футбольних тренувань та відсутністю травм за останні 6 місяців були відібрані в якості суб'єктів дослідження та проходили курс лікування ICEFIT протягом 4 тижнів. Збір даних проводився шляхом вимірювання частоти серцевих скорочень, рівнів ІЛ-6 та індексу втоми як на перед-, так і на післяінтервенційному етапах дослідження. Методи аналізу даних включали використання параметричного t-критерію парних вибірок та t-критерію для незалежних вибірок з рівнем значущості 5 %.

Результати. Результати дослідження показали, що застосування льодової компресії для покращення стану фізичної підготовленості сприяло значному зниженню частоти серцевих скорочень, рівнів ІЛ-6 та індексу втоми спортсменів-футболістів після виконання тренувань на розвиток швидкісної витривалості ($p \leq 0,05$). Крім того, спостерігалося суттєве зниження частоти серцевих скорочень, рівнів ІЛ-6 та індексу втоми між групами ($p \leq 0,05$).

Висновки. Отримані дані демонструють ефективність застосування ICEFIT з метою зниження частоти серцевих скорочень, рівнів IL-6 та індексу втоми спортсменів-футболістів після проведення тренувань на розвиток швидкісної витривалості.

Ключові слова: ICEFIT, прозапальний цитокін, спортсмени-футболісти, тренування на розвиток швидкісної витривалості.

Information about the authors:

Fajar, Muhammad Kharis: muhammadfajar@unesa.ac.id; https://orcid.org/0000-0003-2808-7411; Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Hariyanto, Agus: agushariyanto@unesa.ac.id; https://orcid.org/0000-0002-7927-8827; Department of Sport Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Wahjuni, Endang Sri: endangwahjuni@unesa.ac.id; https://orcid.org/0000-0002-4414-9961; Faculty of Medicine, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Kartiko, Dwi Cahyo: dwicahyo@unesa.ac.id; https://orcid.org/0000-0002-6727-0879; Department of Physical Education, Health and Recreation, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Siantoro, Gigih: gigihsiantoro@unesa.ac.id; https://orcid.org/0009-0000-4377-5218; Department of Sport Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Phanpheng, Yanyong: yanyong.pha@lru.ac.th; https://orcid.org/0000-0002-9290-2479; Sports and Exercise Science Program, Faculty of Science and Technology, Loei Rajabhat University, 234 Loei - Chiang Khan Road, Loei 42000, Thailand.

Kusuma, I Dewa Made Aryananda Wijaya: dewawijaya@unesa.ac.id; https://orcid.org/0000-0002-4939-7294; Department of Sport Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Pramono, Bayu Agung: bayupramono@unesa.ac.id; https://orcid.org/0000-0002-9308-1289; Department of Sport Coaching Education, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Rusdiawan, Afif: afifrusdiawan@unesa.ac.id; https://orcid.org/0000-0001-5388-7061; Department of Sports Science, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Pranoto, Adi: adipranoto@unesa.ac.id; https://orcid.org/0000-0003-4080-9245; Department of Sport Coaching Education, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

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Comparing Physical Attribute Distinctions in Male Kho-Kho Positions

Sarita Tyagi[1ABCDE], Anil Kumar Vanaik[1ABCDE], Monika Wasuja[1ABCDE] and Dessalegn Wase Mola[2CDE]

[1]University of Delhi
[2]Ambo University

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

Corresponding Author: Dessalegn Wase Mola, e-mail: dessalegn.wasie@gmail.com
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Abstract

Background. Kho-Kho, a traditional Indian sport, has separate roles for runners and chasers, each requiring unique physical attributes. Research on the specific physical and anthropometric characteristics of players in this position is limited, highlighting the need for this study to optimize performance at the national level.

Objectives. The study aimed to investigate the differences in physical and anthropometric parameters between national level male Kho-Kho players categorized as Runners and Chasers.

Materials and methods. A total of 200 male Kho-Kho players, aged 17 to 21 years, were selected for the study. The participants were divided into two groups: 100 Runners (average age 19.21 ± 1.15 years) and 100 Chasers (average age 19.29 ± 1.19 years). The physical attributes measured included body weight, height, BMI, arm length, sitting height, chest girth, thigh girth, calf girth, and skinfold thickness at the biceps, triceps, subscapular, and suprailiac regions. The body fat percentage was calculated using the skinfold measurement technique. Data collection tools included a weighing scale for body weight, a flexible metal tape for circumferences and arm length, and a stadiometer for height and sitting height. The mean and standard deviation were computed for each parameter, and an independent samples t-test was used to compare the two groups.

Results. The findings revealed significant differences in weight, BMI, chest, thigh, and calf circumferences, with Chasers having higher values. In contrast, Runners exhibited greater arm length and sitting height. Additionally, there was no considerable difference in height between Runners and Chasers.

Conclusions. The study concluded that Chasers tend to have higher body weight, BMI, and larger circumferences in the chest, thigh, and calf regions, which may be advantageous for their role. Conversely, Runners benefit from longer arm lengths and greater sitting height, which may aid in evading Chasers. These findings suggest that role-specific physical attributes should be considered in training and player selection to enhance performance in Kho-Kho.

Keywords: anthropometry, body composition, chasers, Kho-Kho, physical attributes, runners.

Introduction

Kho-Kho, one of India's oldest traditional team sports, has a rich history rooted in the country's cultural heritage, continues to attract youth even today, maintaining its popularity across the country (Suradkar, 2012; Jacob et al., 2023). It is a dynamic, high-energy game that demands significant physical and mental stamina. The sport is structured around running and chasing, with each team comprising twelve players, of which nine take the field initially. The objective is straightforward: chasers aim to tag the runners of the opposing team, who in turn, strive to evade being caught. The strategic elements of the game are complex, as runners, also known as defenders, must use agility and tactical thinking to avoid being tagged, while chasers must demonstrate speed, endurance, and precision (Manohar, 2015). The game's structure, which restricts chasers to moving in one direction and necessitates running around posts to switch sides, further emphasizes the importance of physical fitness and strategic maneuvering (Kamlesh, 1998).

ТМФВ
ТОВ ОВС

In recent years, there has been a growing interest in understanding the specific physical and physiological requirements necessary to excel in different playing positions in Kho-Kho. This interest stems from the recognition that different roles within the game—chasers and runners—may require distinct physical attributes. For instance, chasers might benefit more from enhanced speed, strength, and endurance, while runners might rely heavily on agility, flexibility, and quick reflexes (Thirumangal, 2013). The identification of these role-specific attributes is crucial not only for optimizing individual performance but also for refining training methods and selection criteria (Kansal et al., 1986; Malhotra et al., 1972).

Adequate hand size, including measurements like shape and length, is essential for strength, precision, and overall athletic performance in court sports (Rahman & Sharma, 2024a) Morphological characteristics are particularly significant in this context because they are largely determined by genetic factors, and a well-established relationship exists between an athlete's morphology and their performance in sports (Norton & Olds 2001). Different body types—whether in terms of size, shape, or proportions—are known to offer advantages in various physical activities. Physical index and body proportions based on anthropometric measurements are vital for assessing player performance in team sports, where specific physical traits are essential for different positions to achieve optimal results (Rahman & Sharma, 2024b). Recent studies have further confirmed that specific anthropometric and somatotype characteristics can provide a competitive edge in sports like Kho-Kho, where the interplay between speed, agility, and endurance is critical (Phukon et al., 2023 and Deepak et al., 2022). Shelke's (2024) study identifies distinct anthropometric traits in elite Kabaddi players, with raiders being taller and defenders having higher mesomorphy. These insights emphasize the need for position-specific training to optimize player development based on their physical profiles. Researcher Thirumangal (2013) emphasized that understanding these correlations can serve as a foundation for identifying the ideal physical profiles for athletes in different roles, potentially leading to more targeted training programs and improved performance outcomes.

Moreover, the evolving nature of sports science has brought to light the importance of tailored fitness regimens that cater to the unique demands of each sporting position. For Kho-Kho, this means that both chasers and runners might require different training focuses to maximize their potential. Chasers, for example, may need to prioritize explosive power and linear speed, whereas runners might benefit from agility drills and exercises aimed at enhancing reaction time and lateral movement (Kamlesh, 1998; Manohar, 2015). The impact of these tailored fitness approaches is evident in the enhanced performance levels observed in athletes who undergo specialized training programs designed to suit their specific roles within the sport.

The game of Kho-Kho demands a unique combination of physical capabilities, requiring Runners and Chasers to excel in speed, agility, strength, and strategic maneuvering. Despite these specific demands, limited research has been conducted to compare the physical and anthropometric attributes of players in these positions. Understanding these differences is crucial for optimizing performance, as tailored physical characteristics may offer a competitive edge in each role. This study aims to bridge this gap by analyzing and comparing the physical attributes of national-level male Kho-Kho players in these two roles, providing valuable insights that could enhance training, selection, and overall performance in the sport.

Material and Methods

Participants

A sample of 200 National-level male Kho-Kho players, aged 17 to 21 years, was selected. This sample included 100 Runners (average age 19.21 ± 1.15 years) and 100 Chasers (average age 19.29 ± 1.19 years). The participants were randomly chosen from active Kho-Kho training centers located in various regions of Delhi and Haryana, India. All subjects were in good physical condition and regularly participated in Kho-Kho.

Instruments and Measurement

The study employed various instruments to measure physical and anthropometric variables. These included a weighing scale for body weight, a stadiometer for measuring height and sitting height, and a flexible metal tape for measuring arm length and various girths (chest, thigh, and calf). Skinfold measurement was taken using a skinfold caliper to assess thickness at the biceps, triceps, subscapular, and suprailiac regions. The body fat percentage was calculated using these four skinfold measurements, applying the Durnin and Womersley equation (1974).All instruments, including the measuring tapes, stadiometer, weighing scale, and skinfold caliper, were calibrated to ensure accuracy.

Statistical Analysis

Descriptive statistics, specifically the mean and standard deviation, were used to describe the physical and anthropometric variables of Runners and Chasers. To compare the differences between these groups, an independent samples t-test was employed. The level of significance for the statistical tests was set at $p < 0.05$.

Results

An independent samples t-test was conducted to compare the physical attributes between runners and chasers. The results indicated that chasers had significantly higher weight, $t_{(198)} = 3.132$, $p = .002$; BMI, $t_{(198)} = 4.330$, $p = .000$; chest circumference, $t_{(198)} = 2.546$, $p = .012$; thigh circumference, $t_{(198)} = 3.545$, $p = .000$; calf circumference, $t_{(198)} = 4.882$, $p = .000$; and body fat percentage, $t_{(198)} = 2.463$, $p = .015$, compared to runners. Conversely, runners had significantly longer arm length, $t_{(198)} = 3.538$, $p = .001$, and greater sitting height, $t_{(198)} = 6.242$, $p = .000$, than chasers. There was no significant difference in height between the two groups, $t_{(198)} = 0.445$, $p = .657$ (table 1, 2; fig. 1).

Discussion

The study aimed to investigate differences in physical and anthropometric parameters between national-level

Table 1. Descriptive Statistics of Runners and Chasers

Variables	Groups	Mean	Std. Deviation	Minimum	Maximum
Age (yr)	Runner	19.21	1.15	17.00	21.00
	Chaser	19.29	1.19	17.00	21.00
Height (cm)	Runner	168.88	6.31	156.30	186.20
	Chaser	168.45	6.16	156.30	187.00
Weight (kg)	Runner	55.95	7.51	43.50	84.00
	Chaser	59.43	8.40	26.60	88.00
BMI(kg/m^2)	Runner	19.61	2.36	14.68	25.64
	Chaser	21.03	2.31	17.17	27.00
Chest Circumference (cm)	Runner	84.89	5.09	70.00	98.00
	Chaser	86.59	4.87	72.00	98.00
Arm Length (cm)	Runner	77.08	2.55	71.10	82.30
	Chaser	75.91	2.14	71.10	80.90
Sitting Height (cm)	Runner	92.89	3.47	85.97	102.41
	Chaser	89.77	3.58	82.97	99.41
Thigh Circumference (cm)	Runner	48.02	4.76	39.50	65.50
	Chaser	50.45	4.71	41.40	67.40
Calf Circumference (cm)	Runner	32.46	2.73	22.60	41.20
	Chaser	34.32	2.73	24.50	43.10
Body Fat (%)	Runner	10.92	1.86	6.35	14.22
	Chaser	11.55	1.76	7.24	14.70

Table 2. Independent t-test comparing physical attributes between runners and chasers

Variable	Groups	n	Mean	MD	df	t	Sig.
Height	Runner	100	168.88	0.39	198	0.445	0.657
	Chaser	100	168.45				
Weight	Runner	100	55.95	3.51	198	3.132	.002*
	Chaser	100	59.43				
BMI	Runner	100	19.61	1.42	198	4.330	.000*
	Chaser	100	21.03				
Chest Circumference	Runner	100	84.89	1.77	198	2.546	.012*
	Chaser	100	86.59				
Arm Length	Runner	100	77.08	1.74	198	3.538	.001*
	Chaser	100	75.91				
Sitting Height	Runner	100	92.89	3.09	198	6.242	.000*
	Chaser	100	89.77				
Thigh Circumference	Runner	100	48.02	2.37	198	3.545	.000*
	Chaser	100	50.45				
Calf Circumference	Runner	100	32.46	1.88	198	4.882	.000*
	Chaser	100	34.32				
Body Fat	Runner	100	10.92	0.631	198	2.463	.015*
	Chaser	100	11.55				

*Significant at 0.05 level

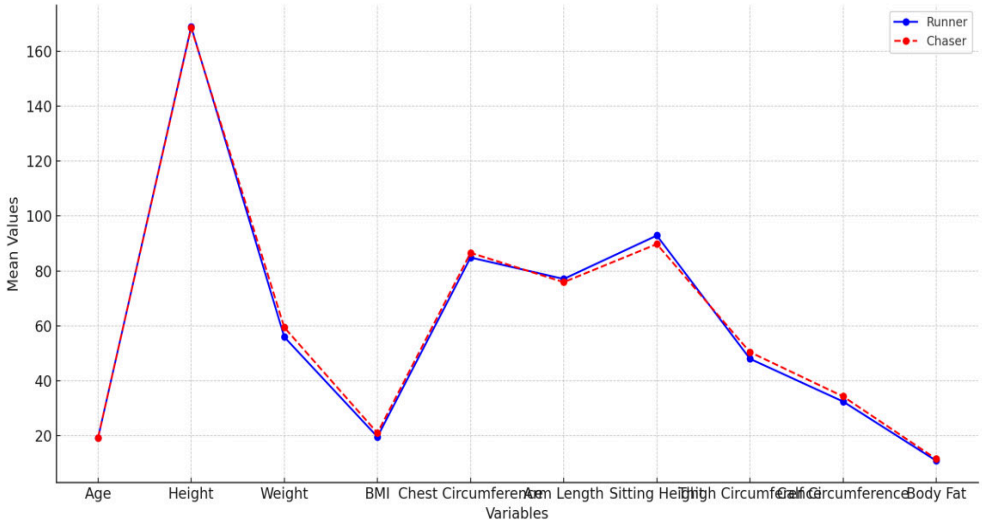

Fig. 1. Comparison of Physical Characteristics between Runners and Chasers

male Kho-Kho players categorized as Runners and Chasers. Results indicated that Chasers had significantly higher weight, BMI, chest circumference, thigh circumference, calf circumference, and body fat percentage compared to Runners. Conversely, Runners had longer arm lengths and greater sitting heights, though height differences were not significant. These findings highlight that physical attributes such as body composition and limb measurements are crucial for performance in Kho-Kho, reflecting the importance of specific biomotor abilities like speed, agility, and power (Kumar and Arumugam, 2018).

Consistent with Kumar and Arumugam (2018), the study emphasizes the importance of speed, agility, and power in Kho-Kho performance, highlighting these biomotor abilities as crucial for success in the sport. The comparison with Rickta et al. (2024), shows that Kho-Kho players possess slightly longer leg lengths and lower body fat percentages compared to football players, suggesting a potential physical advantage that could influence their performance. Furthermore, Jaiswal (2014) supports these observations by noting that Kho-Kho players exhibit greater height and lean body mass, contributing to their enhanced athleticism. The findings underline the lean and muscular physique of Kho-Kho players, which may be pivotal for their effectiveness in the sport.

Research by Bhati et al. (2023) and Mahapatra and Abhinandan (2023) emphasizes the importance of fluid intake, sleep quality, and lean body mass as critical factors in optimizing Kho-Kho performance, with fluid intake enhancing speed and sleep and lean mass supporting agility and power. These findings highlight the value of training programs that integrate hydration, nutrition, and sleep quality to improve athletic outcomes. Consistent with Taye et al. (2024), this research reinforces the importance of nutrition education, advocating for balanced fat intake and addressing nutritional deficiencies, which can promote both immediate performance gains and long-term health benefits for athletes. The moderate correlation between speed and agility, with a stronger relationship observed in boys, suggests that while these attributes are essential for Kho-Kho, their impact may vary by gender. The studies by Mahapatra and Abhinandan (2023), along with Mola and Shaw (2024a, 2024b), provide a comprehensive framework for talent development and identification in athletic practice. Mahapatra and Abhinandan (2023) highlight a moderate correlation between speed and agility, crucial for distinguishing performance roles between Runners and Chasers. Meanwhile, Mola and Shaw (2024a) emphasize long-term development, quality preparation, and a supportive environment, while Mola and Shaw (2024b) propose a multi-dimensional approach to talent identification, focusing on anthropometric, sociological, physiological, psychological, and technical predictors. Together, these studies offer valuable insights that support targeted training and effective talent identification to enhance Kho-Kho players performance.

Conclusions

The study identified significant physical differences between Runners and Chasers in National-level Kho-Kho players. Chasers tend to have higher weight, BMI, and larger chest, thigh, and calf circumferences, along with greater body fat, indicating greater mass and stability. Runners, however, have longer arm lengths and greater sitting height, quick reflexes skills. The lack of difference in height suggests it is not a key factor in role performance. Based on these findings, it is recommended that training and selection be tailored to the specific physical demands of each role to optimize team performance.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Порівняльний аналіз відмінностей фізичних характеристик чоловіків-гравців у Кхо-Кхо щодо позицій гри

Саріта Т'ягі[1ABCDE], Аніл Кумар Ваная[1ABCDE], Моніка Васуджа[1ABCDE], Дессален Васе Мола[2CDE]

[1]Делійський університет
[2]Університет Амбо

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

Реферат. Стаття: 6 с., 2 табл., 1 рис., 22 джерела.

Історія питання. Кхо-Кхо – традиційний індійський вид спорту, що складається з виконання окремих функцій для бігунів та ловців, кожна з яких вимагає від гравців наявності унікальних фізичних якостей. Наукові праці щодо специфічних фізичних та антропометричних характеристик гравців зазначеної позиції мають обмежений характер, що підкреслює необхідність проведення таких досліджень задля оптимізації результативності на національному рівні.

Мета дослідження. Дослідження мало на меті вивчити відмінності у фізичних та антропометричних параметрах між чоловіками-гравцями у Кхо-Кхо національного рівня, які поділяються на категорії «бігунів» та «ловців».

Матеріали та методи. З метою проведення дослідження було відібрано 200 гравців чоловічої статі, віком від 17 до 21 року. Учасників було розподілено на дві групи: 100 бігунів (середній вік 19,21 ± 1,15 року) та 100 ловців (середній вік 19,29 ± 1,19 року). Фізичні показники, що вимірювалися, включали масу тіла, зріст, ІМТ, довжину рук, зріст у положенні сидячи, обхват грудної клітки, обхват стегон, обхват литок і товщину шкірної складки на біцепсі, трицепсі, підлопатковій і надклубовій ділянках. Розрахунок відсоткового вмісту жиру в організмі проводився за допомогою методу вимірювання товщини шкірної складки. Інструменти збору даних включали ваги для вимірювання маси тіла, гнучку металеву стрічку для визначення окружності та довжини рук, а також ростомір для вимірювання зросту та показників зросту в положенні сидячи. За кожним параметром розраховували середнє значення та стандартне відхилення, а з метою порівняльного аналізу двох груп — використовували t-критерій для незалежних вибірок.

Результати. За результатами дослідження встановлено значні відмінності у показниках ваги, ІМТ, окружності грудної клітки, стегон та литок, зокрема, вищі показники спостерігалися у ловців. Натомість бігуни мали більші показники довжини рук і зросту у положенні сидячи. Крім того, не спостерігалося суттєвої різниці у показниках зросту між бігунами та ловцями.

Висновки. Згідно з результатами дослідження було визначено, що ловці, як правило, мають більшу масу тіла, ІМТ та вищі показники окружностей ділянок грудної клітки, стегон та литок, що може бути перевагою для виконання їхньої функції у грі. Натомість бігуни отримують перевагу від більшої довжини рук і вищих показників зросту в положенні сидячи, що може сприяти уникненню ловців. Отримані дані свідчать про необхідність врахування специфічних для певної функції фізичних характеристик під час тренувань та відбору гравців з метою підвищення результативності гри Кхо-Кхо.

Ключові слова: антропометрія, композиція тіла, ловці, Кхо-Кхо, фізичні характеристики, бігуни.

Information about the authors:

Tyagi, Sarita: sarita.igipess@gmail.com; https://orcid.org/0009-0007-8418-5389; Department of Physical Education and Sports Science, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Vanaik, Anil Kumar: anilvanaik4@gmail.com; https://orcid.org/0009-0005-2053-2148; Department of Physical Education and Sports Science, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Wasuja, Monika: monikawasuja@gmail.com; https://orcid.org/0009-0002-5065-1656; Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Mola, Dessalegn Wase: dessalegn.wasie@gmail.com; https://orcid.org/0000-0001-9688-0775; Department of Sports Science, Ambo University, Ambo, Ethiopia.

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Analyzing the Effect of Dancesport on Reducing Menopausal Symptoms and Increasing Quality of Life

Noortje Anita Kumaat[1ABCDE], Soni Sulistyarto[1ABD], Ratna Candra Dewi[1CD], Heri Wahyudi[1ACD], Caturia Sasti Sulistyana[1ABCD], Nugroho Susanto[2ADE], Ozgur Eken[3CDE] and Septyaningrum Putri Purwoto[4BCDE]

[1]State University of Surabaya
[2]Inonu University
[3]Universitas Negeri Padang
[4]STKIP PGRI Bangkalan

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

Corresponding Author: Noortje Anita Kumaat, e-mail: noortjeanita@unesa.ac.id
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Abstract

Background. The increasing popularity of dancesport is being observed worldwide, with Indonesia also embracing this trend. Nevertheless, there is still a lack of data to establish if dancesport can help with menopausal symptoms and enhance quality of life.

Objectives. This study aimed to investigate the impact of a 12-week dancesport program on decreasing menopausal symptoms and improving quality of life.

Materials and methods. A quasi-experimental design was used with a pretest-posttest method. The study included 30 women who had gone through menopause and were between the ages of 54 and 63. The WHOQOL-BREF questionnaire was used to evaluate the quality of life, and the Menopause Rating Scale (MRS) was employed to assess the severity of menopausal symptoms. The program involved a 12-week dance course, meeting twice a week for 60 minutes per session, including cha-cha, salsa, rumba, hip-hop, and waltz dances. Data analysis was conducted using SPSS 24, beginning with descriptive statistics, then progressing to normality testing using the Shapiro-Wilk test, and finally paired samples t-tests.

Results. The findings indicated a noteworthy influence of the 12-week dancesport intervention on menopausal symptoms and quality of life, with a significance level of 0.000 (< 0.05).

Conclusions. The study found that dancesport is beneficial for postmenopausal women by improving symptoms and quality of life, suggesting further research into the impact of these programs on men experiencing andropause-related changes.

Keywords: dancesport, menopausal symptoms, quality of life, menopausal women.

Introduction

Studies indicate that menopausal symptoms impact around half of middle-aged women in different countries (Fang et al., 2024). Menopause indicates the stoppage of ovarian follicular activity and signals the conclusion of a woman's fertility period (Hettchen et al., 2021). This time is important for numerous women who remain involved in society and their personal lives while dealing with related symptoms (Vaccaro et al., 2021). Menopause is a normal, natural change that occurs in middle age, causing women to experience various difficulties that affect their quality of life (Mendoza-Huertas et al., 2024). Numerous women look for different methods to reduce the severity of these symptoms, and exercise is among the suggested choices (Dabrowska-Galas, 2019). It is important to prioritize both physical and mental health with consistent exercise during menopause (Guna et al., 2024; Spector et al., 2024). Physical activity emerges as a hopeful non-medical solution to tackle the various risk factors linked to menopause (Hettchen et al., 2021; Mansikkamaki, 2016).

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Nguyen (2022) found that engaging in physical activity can help alleviate menopausal symptoms and boost the overall quality of life for women (Nguyen et al., 2022). Women who participate in moderate to high levels of physical activity have milder menopausal symptoms in comparison to those who are not active, according to (Dąbrowska-Galas et al., 2019). Engaging in aerobic workouts can greatly help in relieving specific menopause symptoms (Money et al., 2024). Earlier research has shown a strong connection between the amount of physical activity and the well-being of women going through menopause, emphasizing how regular physical activity can have a lasting positive influence on their health-related quality of life (Fauntroy et al., 2020). Studies have also investigated shifts in menopause risk factors in recently menopausal women with osteopenia after participating in high-intensity exercise for 13 months (Hettchen et al., 2021).

Dancesport, growing in global popularity and also in Indonesia (Suhaya et al., 2024), combines art and physical activity as a form of exercise (Holt, 2017). Dance blends athleticism with artistry by incorporating intricate movements, a wide range of motion, and musicality to create a unique form of expression (Fauntroy et al., 2020). Line dance is highly favored because it combines fitness and dance effectively, providing various health benefits for both the body and mind, thereby increasing its widespread popularity (Guo, 2022). Moreover, research has demonstrated that square dancing can boost cognitive function in elderly individuals (Wang et al., 2024), and engaging in Pilates or Zumba for at least 12 weeks can improve functional performance, mood, and the quality of life in postmenopausal women (Ben Waer et al., 2024).

Women experiencing intense symptoms during menopause frequently indicate reduced health-related quality of life (Money et al., 2024), which involves the impact of physical health on mental and social welfare (Schneider, 2002). In menopause, the decrease in ovarian activity and reproductive hormone levels can result in different health issues that impact a woman's overall well-being (Guna et al., 2024).

Based on this evidence, the theory of this research is that dancing workouts can lessen menopausal symptoms and enhance quality. However, there are still no studies on dance sports in menopausal women in Indonesia, and its impact on menopausal symptoms and increased quality of life in menopausal women in Indonesia is still unknown.

Based on existing theories, the hypothesis in this study is that dance exercise can reduce menopausal symptoms and improve quality of life. So this study aims to determine the effect of 12 weeks dance sport to reduce menopausal symptoms and increase quality of life.

Materials and Methods

Study Participants

The research included 30 postmenopausal women, aged between 54 and 63, who were selected from the local community. In order to join, participants must have been in their postmenopausal stage for a minimum of 12 weeks and not have any health issues that could hinder their participation in the workout regimen. Approval for this research was authorized by the Health Research Ethics Committee at Nahdlatul Ulama University of Surabaya, with ethical clearance number 0400/EC/KEPK/UNUSA/2024.

Table 1. Participant characteristics

	Information
Age	57.66 ± 2.48
Weight	59.76 ± 8.87
Height	163.21 ± 7.63
Bloodpresure	120.71 ± 9.97
Education	Bachelor: 19 Senior high school: 11
Work	Enterpreneur: 3 Government employees: 3 Teacher: 6 Private employess:10 Housewife: 7 Teacher retirement:1
Status	Married: 25 Widow: 5

The characteristics of the samples in this study are presented in the table above, including age, weight, height, blood pressure, education, occupation and status.

Study Organization

This research employed a quasi-experimental design incorporating pretest-posttest methodology to assess the impact of a dance exercise program on quality of life and Menopause Rating Scale (MRS) scores among postmenopausal women. The WHOQOL-BREF questionnaire was used to evaluate quality of life (Guna et al., 2024), including physical health, mental health, social relationships, and environmental factors. The Menopausal Rating Scale (MRS) was employed to assess the intensity of menopausal symptoms, showing high test-retest reliability between 0.90 and 0.95 and construct validity scores of 0.92, 0.93, and 0.95, demonstrating the tool's validity and reliability (Dwi Susanti et al., 2019). In the pretest, the participants filled out the WHOQOL-BREF and MRS surveys to collect initial information on their quality of life and menopausal symptoms. The program involved 12 weeks of dance exercises, with participants going to two 60-minute sessions a week, including dances like cha-cha, salsa, rumba, hip-hop, and waltz. After the 12-week program, participants were asked to complete the same questionnaires for another evaluation of their quality of life and menopausal symptoms.

Statistical Analysis

Statistical analysis in this study used SPSS 24 which includes descriptive tests, followed by normality tests using Shapiro-Wilk and T tests with Paired Samples Tests to determine the effect of dance sports for 12 weeks on the menopausal symptoms and quality of life of menopausal women.

Results

The results section will provide a detailed analysis of the statistical data, examining the impact of a 12-week dancesport program on menopausal symptoms and the quality of life in postmenopausal women. This will include the findings from descriptive statistics, normality tests, and Paired Samples Tests.

Table 2. Descriptive statistics

Group	n	Min	Max	Mean	SD
Pre MS	30	32	39	35.90	2.398
Post MS	30	19	27	22.87	2.515
Pre QL	30	76	89	82.20	4.038
Post QL	30	100	122	110.27	6.539

Information: Pre MS (Pre test menopausal symtoms), Post MS (Post test menopausal symtoms), Pre QL (Pre test quality of life), Post QL (Post test quality of life).

Table 2 demonstrates that the 12-week dancesport program had a significant effect on menopausal symptoms and quality of life in postmenopausal women. The mean score for menopausal symptoms decreased from 35.90 in the pre-test to 22.87 in the post-test, while the mean score for quality of life improved from 82.20 in the pre-test to 110.27 in the post-test.

Table 3. Test of normality (Shaphiro-Wilk)

Group	Statistic	df	Sig.
Pre MS	.905	30	.011
Post MS	.914	30	.019
Pre QL	.965	30	.414
Post QL	.943	30	.108

The results in table 3 show that the overall data distribution obtained normal results because all sig results > 0.05. Then the Paired Samples Test can be carried out.

Table 4. Paired samples test

Group	Sig
Menopausal Symtoms	.000
Quality of Life	.000

The table results show that both menopausal symptoms and quality of life variables had significance values of 0.000, lower than the threshold of 0.05. This validates that the 12-week program for dancesport significantly decreased menopausal symptoms and enhanced the quality of life in postmenopausal women.

Discussion

The results of this study are consistent with earlier studies that have demonstrated the positive impact of dance on women's quality of life (Hernandes et al., 2018). In the same way, research has shown that activities such as Pilates or Zumba can enhance functional performance, mood, and health-related quality of life in postmenopausal women after 12 weeks (Ben Waer et al., 2024). Engaging in workout routines that reduce menopausal symptoms may enhance the quality of life for women who have gone through menopause (Shin & Lee, 2021). According to Adi Wira Guna (2024), dance-based workouts have been proven to enhance physical function, which may improve ovarian function and reproductive hormone levels (Yang & Toriola, 2024), leading to a reduction in health problems and an overall improvement in quality of life (Guna et al., 2024).

Following menopause, there is a substantial decrease in estrogen levels, resulting in the appearance of androgenic manifestations like acne, heightened facial hair growth, and male-pattern baldness. Androgens impact sexual desire, arousal, and climax by increasing dopamine levels in the central nervous system (Brzozowska & Lewiński, 2021). A woman's daily physical activity level greatly affects her quality of life during menopause (Fauntroy et al., 2020). According to Adi Wira Guna (2024), women who consistently engage in physical activity experience an improved quality of life due to enhanced endurance and decreased chances of chronic illnesses (Guna et al., 2024).

Dancing is a highly favored method of staying in shape that offers not just physical advantages, but also boosts mental and emotional health, making it a preferred pastime for numerous individuals (Guo, 2022). Dance merges physical activity with social and emotional advantages, enhancing self-expression, self-worth, and self-assurance while reducing stress (Hernandes et al., 2018). It also makes social interaction, motivation, and positive emotions easier (Hernandes et al., 2018). Furthermore, dance interventions have been found to have beneficial impacts on physical function, postural control, and quality of life (Lu et al., 2024). These advantages aid in decreasing menopausal symptoms and enhancing overall quality of life (Fang et al., 2024). Dancing helps increase physical activity levels, leading to improved muscle movement, better distribution of nutrients and oxygen, and maintenance of fitness, bone density, muscle strength, and joint mobility, all of which contribute to overall physical and physiological well-being (Guna et al., 2024).

Based on the discussion above, it is recommended that menopausal women do dance sports to reduce menopausal symptoms and increase quality of life.

Conclusions

Based on the research results, it was found that after doing dance sports for 12 weeks, it can reduce menopause symptoms and improve the quality of life of menopausal women. The limitation of this study is that it only provides sport in the form of dancesport.

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Conflict of Interest

The authors report no conflict of interest.

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Аналіз впливу спортивних танців на зниження симптомів менопаузи та підвищення якості життя

Нуртьє Аніта Кумаат[1ABCDE], Соні Сулистярто[1ABD], Ратна Чандра Деві[1CD], Гері Вахюді[1ACD], Катурія Касті Сулістяна[1ABCD], Нугрохо Сусанто[2ADE], Озгур Екен[3CDE], Септянінгрум Путрі Пурвото[4BCDE]

[1]Сурабайський державний університет

[2]Падангський державний університет

[3]Університет імені Ісмета Іненю

[4]Бангкаланський педагогічний коледж Асоціації вчителів Індонезії

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

Реферат. Стаття: 5 с., 4 табл., 23 джерела.

Історія питання. Зростаюча популярність спортивних танців спостерігається в усьому світі, зокрема, в Індонезії, яка також приєдналася до цієї тенденції. Однак досі бракує даних, які б дозволили встановити, чи можуть заняття спортивними танцями допомогти впоратися з симптомами менопаузи та покращити якість життя.

Мета дослідження. Мета дослідження полягала у вивченні впливу 12-тижневої програми занять спортивними танцями на зменшення симптомів менопаузи та поліпшенні якості життя.

Матеріали та методи. У представленій науковій праці застосовано квазіекспериментальний дизайн із використанням методики перед- і післятестового дослідження. У дослідженні взяли участь 30 жінок, які пройшли через менопаузу у віці від 54 до 63 років. Для оцінки якості життя використовували опитувальник WHOQOL-BREF, а з метою визначення ступеня важкості менопаузальних симптомів — міжнародну шкалу з оцінки симптомів менопаузи ("Menopause Rating Scale", MRS). Програма передбачала 12-тижневий курс занять спортивними танцями, що проводилися двічі на тиждень із тривалістю 60 хвилин кожне заняття, включаючи ча-ча-ча, сальсу, румбу, хіп-хоп і вальс. Аналіз даних проводився за допомогою програмного забезпечення SPSS 24, починаючи з описової статистики, після чого здійснювався тест на перевірку нормальності розподілу із застосуванням критерію Шапіро-Уілка і, зрештою, завершальний етап передбачав використання t-критеріїв для парних вибірок.

Результати. Отримані дані свідчать про значний вплив 12-тижневої інтервенції зі спортивних танців на симптоми менопаузи та якість життя з рівнем значущості 0,000 (< 0,05).

Висновки. За результатами дослідження встановлено, що заняття спортивними танцями корисні для жінок у постменопаузальному періоді, оскільки покращують симптоми та якість життя, що спонукає до подальших досліджень щодо впливу зазначених програм на чоловіків, які переживають зміни, пов'язані із періодом андропаузи.

Ключові слова: спортивні танці, симптоми менопаузи, якість життя, жінки у менопаузальному періоді.

Information about the authors:

Kumaat, Noortje Anita: noortjeanita@unesa.ac.id; https://orcid.org/0000-0001-6045-7553; Department of Sports Science, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Sulistyarto, Soni: sonisulistyarto@unesa.ac.id; https://orcid.org/0000-0003-4201-856X; Department of Sports Science, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Dewi, Ratna Candra: ratnadewi@unesa.ac.id; https://orcid.org/0000-0003-0612-244X; Department of Nutrition, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Wahyudi, Heri: heriwahyudi@unesa.ac.id; https://orcid.org/0009-0000-1355-6954; Sports Science Department, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Sulistyana, Caturia Sasti: ns.sulistyana@unesa.ac.id; https://orcid.org/0000-0002-1993-3682; Department of Nursing, Faculty of Medicine, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Susanto, Nugroho: nugrohosusanto@fik.unp.ac.id; https://orcid.org/0000-0002-9184-2769; Department of Health and Recreation, Universitas Negeri Padang, Jl. Prof. Dr. Hamka No.1, Air Tawar Bar., Kec. Padang Utara, Kota Padang, Sumatera Barat 25173, Indonesia.

Eken, Ozgur: ozgureken86@gmail.com; https://orcid.org/0000-0002-9184-2769; Department of Physical Education and Sport Teaching, Faculty of Sports Sciences, Inonu University, Malatya-Elazig-Road 15 km, 44280 Battalgazi/Malatya, Turkey.

Purwoto, Septyaningrum Putri: septyaningrum@stkippgri-bkl.ac.id; https://orcid.org/0000-0003-2765-3960; Study Program of Sports Education, STKIP PGRI Bangkalan, Jl. Soekarno Hatta No.52, Mlajah, Kec. Bangkalan, Kabupaten Bangkalan, Jawa Timur 69116, Indonesia.

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Original Scientific Article

Measuring the Impact of COVID-19 on Young Adult Functional Capacity: A Comparative Study of Walking and Step Endurance Tests

Patchareeya Amput[1ACD], Arunrat Srithawong[1ABCD], Sinthuporn Maharan[1ADE], Puttipong Poncumhak[1ABCD], Patcharin Phrompao[1CD], Eakarach Wongsaya[1CD], Tichanon Promsrisuk[1ABCD] and Sahachat Aueyingsak[2ACD]

[1]University of Phayao
[2]Christian University of Thailand

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

Corresponding Author: Arunrat Srithawong, e-mail: arunrat.sr@up.ac.th
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Abstract

Objectives. This study aimed to evaluate and compare the functional capacity of young adults recovering from COVID-19 using the 6-Minute Walk Test (6MWT) and 2-Minute Step Test (2MST), focusing on cardiovascular parameters, and to examine correlations between these tests, demographic factors, and muscle strength.

Materials and methods. A cross-sectional study was conducted with 34 young participants (mean age: 20.62 years, 88.24 % female), all experiencing mild post-COVID-19 symptoms. Muscle strength (grip and quadriceps strength) was assessed, and functional capacity was evaluated using the 6MWT and 2MST, with the test order randomized by drawing lots. Hemodynamic responses, fatigue, and dyspnea were measured before and after both tests. Paired t-tests were used to compare cardiovascular parameters and leg fatigue between the 6MWT and 2MST. Pearson's correlation coefficient assessed relationships between both tests, demographics, and muscle strength.

Results. The study revealed an increase in heart rate and leg fatigue after the 6MWT compared to the 2MST, whereas systolic blood pressure was elevated following the 2MST compared to the 6MWT. The 6MWT showed a significant positive correlation with the 2MST ($r = 0.350$, $p = 0.043$). Additionally, quadriceps strength was positively correlated with both the 6MWT ($r = 0.372$, $p = 0.030$) and the 2MST ($r = 0.395$, $p = 0.021$).

Conclusions. The findings of this study indicate that both the 6MWT and 2MST are effective in assessing functional capacity in young individuals recovering from COVID-19, showing distinct physiological responses. Furthermore, quadriceps strength is correlated with both tests, highlighting the importance of muscle strength in recovery.

Keywords: COVID-19, physical fitness tests, functional fitness, cardiorespiratory endurance.

Introduction

Severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) primarily affects the respiratory system, but it also causes systemic symptoms, such as fatigue, muscle weakness, and exercise intolerance, that can persist for over 4 weeks or even months in many individuals following the acute phase of infection (Parotto et al., 2023; Weldon et al., 2023). These long-term effects extend beyond lung function, significantly impairing recovery, functional capacity, and quality of life (Alahmari et al., 2023), while also complicating rehabilitation despite normal lung function (Daynes et al., 2024; Wade, 2020). For young adults recovering from COVID-19, assessing functional capacity is essential to identify physical impairments and guide rehabilitation. This evaluation highlights obstacles to daily activities and directs interventions to promote full recovery (Torres-Castro et al., 2023).

Assessing fitness components, especially cardiorespiratory fitness, is vital for precise exercise prescription (Harber et al., 2024; Kaminsky et al., 2024; Ross et al., 2016). It is closely linked to cardiovascular health and is a key indicator of the risk of cardiovascular events and mortality. Evaluating

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this fitness component allows for personalized interventions that reduce health risks and improve long-term well-being (Harber et al., 2024). In clinical practice, cardiorespiratory fitness is often assessed using tests that require advanced equipment, such as treadmills or cycle ergometers, which may not be available in resource-limited settings (Noonan & Dean, 2000). Time-limited walking, sit-to-stand, and step tests are essential for assessing functional status and prognosis in individuals with cardiorespiratory conditions. These tests are safe, effective, and offer critical insights into submaximal exercise capacity, endurance, and daily functional ability, which are key for managing chronic conditions and improving quality of life (Andrade et al., 2012; Cruz-Montecinos et al., 2024; Torres-Castro et al., 2023). For this reason, tests based on the ability to perform daily living tasks are gaining popularity for assessing cardiorespiratory fitness. Functional assessments, particularly walking tests, play a vital role in evaluating daily task performance and overall physical function (Medicine, 2013), especially in post-COVID-19 recovery. Walking requires the coordination of cardiovascular and musculoskeletal systems, and impairments can increase energy expenditure and oxygen demand, complicating recovery (Singh et al., 2014). The 6-Minute Walk Test (6MWT) widely used in clinical settings, measures submaximal aerobic endurance, offering key insights into cardiovascular and muscular function, particularly in cases of heart failure and pulmonary diseases (American Thoracic Society, 2002; Casillas et al., 2013; Holland et al., 2014).

The 6MWT is a simple, cost-effective test that evaluates walking capacity and daily activity performance. Although practical and versatile, it requires a 30-meter hallway and can be time-consuming for routine outpatient visits (Jones & Rikli, 2002; Poncumhak et al., 2023). The 2-Minute Step Test (2MST) is a popular alternative, especially for patients unable to complete the 6MWT. It requires minimal space and no special equipment, making it suitable for resource-limited settings (Bohannon & Crouch, 2019; Jones & Rikli, 2002). It involves marching in place with high knee lifts, providing a less demanding method to assess aerobic endurance (Jones & Rikli, 2002). However, there's no clear consensus on which test provides a more accurate functional assessment, as studies have yielded mixed results. The 2MST replicates physically demanding daily activities, such as stair climbing, which is especially challenging for heart failure patients (Węgrzynowska-Teodorczyk et al., 2016) and older adults (Poncumhak et al., 2023) compared to walking on flat surfaces. Some authors suggest that it should be used as a complement rather than a substitute for other fitness assessments (Węgrzynowska-Teodorczyk et al., 2016). This approach offers valuable insights into functional capacity and real-life physical performance. The objective of this study was to evaluate and compare the physical functional capacity of young adults recovering from COVID-19 using the 6MWT and 2MST, with a focus on cardiovascular parameters. Additionally, the study aimed to explore the correlations between these tests, demographic factors, and muscle strength in post-COVID-19 young adults.

Materials and Methods

Study Participants

This cross-sectional analytical study calculated the sample size using a dependent t-test in G*Power version 3.1.9.4, with an alpha level set at 0.05 and a power of 0.80. A total of 34 participants (30 females and 4 males, aged 18 to 25 years) were recruited through face-to-face contact and posters. These participants were outpatients with mild post-COVID-19 symptoms, having been diagnosed with COVID-19 that did not require hospitalization and discharged within four weeks before evaluation. Exclusion criteria included pre-existing cardiorespiratory, neurological, or musculoskeletal conditions that could influence test performance, a body mass index (BMI) over 30 kg/m^2, and oxygen saturation (SpO_2) levels below 95 %. The study was approved by the University of Phayao Ethics Committee (reference number: HREC-UP-HSST 1.2/089/67).

Study Organization

In the initial phase of the study, participants were interviewed to collect data on age, medical history, and their experience with COVID-19. Anthropometric measurements (height, weight, and BMI), sociodemographic details (age, gender), and clinical information (comorbidities, smoking status, exercise habits) were also recorded. Vital signs, including heart rate (HR), blood pressure (BP), and peripheral oxygen saturation (SpO_2), were measured. Hand grip strength and quadriceps muscle strength were assessed. Functional capacity was evaluated using the 6MWT and 2MST by blind assessors, uninvolved in the interviews.

Grip Strength

Grip strength was measured using a dynamometer (T.K.K 5001 Grip-A, Takei Scientific Instruments, Niigata, Japan), a standard tool with excellent reliability commonly used to assess upper limb strength in adults (Horn et al., 2024). Participants squeezed the device with their dominant hand for three seconds while standing with their arm straight and slightly abducted. The test was repeated three times, with one-minute rest intervals, and the highest score (in kilograms) was recorded (Savas et al., 2023).

Quadriceps Muscle Strength

Quadriceps muscle strength was assessed using a hand-held dynamometer (Model-01165, Lafayette Instrument Company, Lafayette IN, USA), a reliable and valid tool for measuring isometric lower limb muscle strength and power in adults (Mentiplay et al., 2015). The participant, seated with the hip and knee flexed at 90 degrees, performed maximal isometric knee extension with the dominant lower extremity. The test was repeated at least three times, and the highest recorded value (in kilograms) was documented (Brown & Weir, 2001).

Functional Capacity

Participants completed the 6MWT and 2MST on the same day, with a 30-minute rest interval between the tests to reduce muscle fatigue. The order of the tests was randomized by drawing lots. Prior to and immediately after each test, participants were seated, and their SBP, DBP HR and SpO_2 were recorded. Participants also rated their subjective levels of fatigue and dyspnea using a modified 10-point Borg scale,

and dyspnea was assessed with the Borg Rating of Perceived Exertion (RPE) scale (6-20 scale).

6MWT

Before the test, participants were given at least 10 minutes of rest in a seated position to ensure they were adequately prepared. The test was conducted along a 30-meter corridor, and participants were instructed to walk as far as possible within a 6-minute period. Running was prohibited, and participants were encouraged to walk at a comfortable pace, with the option to slow down or stop briefly if needed. The total distance covered during the 6MWT was measured and recorded to assess physical functional capacity (American Thoracic Society, 2002).

2MST

Participants rested for at least 10 minutes before the test. After a brief familiarization session, they marched in place for two minutes, lifting their knees to a height between the patella and iliac crest. They could use support and adjust speed as needed. The investigator counted the steps on the right knee, with the final score representing the total number of steps where the knee reached the specified height (Jones & Rikli, 2002).

Statistical Analysis

Data analysis was conducted using Stata version18. Descriptive statistics, including mean, standard deviation, and frequency, were used to summarize participants' demographic and clinical characteristics. Paired t-tests were employed to compare HR, SBP, DBP, and leg fatigue between the 6MWT and the 2MST, while the Signed Rank Test was used for SpO_2 and dyspnea measurements. Pearson's correlation coefficient was calculated to examine the relationships between 6MWT and 2MST outcomes, demographic factors (age, weight, height, BMI), and muscle strength (hand grip and quadriceps strength). A p-value of less than 0.05 was considered statistically significant.

Results

Table 1 presents the clinical characteristics of 34 participants recovered from mild COVID-19. The mean age was 20.62 years, with 88.24 % being female. The average height, weight, and BMI were 159.88 cm, 54.97 kg, and 20.21 kg/m², respectively. Participants were 3.70 ± 6.38 months post-recovery. Most participants (91.18%) were non-smokers, and 17.65 % reported exercising ≥3 days per week. Functional capacity was evaluated using the 6-Minute Walk Distance (577.76 ± 29.02 meters), the 2-Minute Step Test (115.76 ± 13.44 repetitions), quadriceps strength (20.31 ± 4.85 kg), and handgrip strength (22.83 ± 7.26 kg).

The 6MWT resulted in a significantly higher final HR (120.41 ± 19.68 bpm) compared to the 2MST (111.09 ± 16.74 bpm, p = 0.009). SBP was significantly higher at the end of the 2MST (131.74 ± 17.16 mmHg) than the 6MWT (124.97 ± 14.94 mmHg, p = 0.006). There was no significant difference in DBP between the 2MST (81.41 ± 9.37 mmHg) and the 6MWT (79.15 ± 7.66 mmHg, p = 0.05). Dyspnea scores showed no significant differences between the two tests at baseline (p = 0.07) or at the final stage (p = 0.20). However, leg fatigue was significantly lower in the 2MST (2.59 ± 1.12) compared to the 6MWT (3.34 ± 1.52, p = 0.007) (Table 2).

Table 1. Clinical and functional characteristics of 34 mild-post COVID-19 individuals

Characteristics	n (%) or Mean ± SD	Min-max
Age (years)	20.26 ± 0.61	
Sex (female)	3.000 (88.24)	
Height (cm)	159.88 ± 8.22	
Weight (kg)	54.97 ± 15.31	
BMI (kg/m²)	20.21 ± 5.48	
Duration after COVID (months)	3.70 ± 6.38	
No coexisting diseases	34.00 (100)	
Smoking history		
No smoker	31.00 (91.18)	
Active smoker	2.00 (5.88)	
Former smoker	1.00 (2.94)	
Exercise habits, number		
≥3 days/week	6.00 (17.65)	
1-2 days/week	15.00 (44.12)	
No exercise	13.00 (38.24)	
Physical measures		
6MWD (meters)	577.76 ± 29.02	523.00 - 624.00
2MST (repetitions)	115.76 ± 13.44	76.00 - 185.00
Quadricep strength (kg)	20.31 ± 4.85	14.00 - 32.50
Grip strength (kg)	22.83 ± 7.26	12.00 - 42.10

BMI, body mass index; 6MWD; 6-minute walk distance, 2MST, 2-minutes step test, kg; kilogram

Table 2. Comparison of hemodynamic responses, fatigue, and dyspnea severity to 6MWT and 2MST in mild-post-COVID-19 individuals

Variables	2MST	6MWT	p
HR baseline (bpm)	91.24 ± 12.19	89.27 ± 13.27	0.29
HR final (bpm)	111.09 ± 16.74	120.41 ± 19.68	0.009*
SpO_2 baseline (%)	97.88 ± 0.17	97.71 ± 0.16	0.37
SpO_2 final (%)	98.03 ± 0.83	97.74 ± 0.79	0.13
SBP baseline (mmHg)	115.77 ± 13.44	112.71 ± 13.65	0.06
SBP final (mmHg)	131.74 ± 17.16	124.97 ± 14.94	0.006*
DBP baseline (mmHg)	75.85 ± 9.24	75.59 ± 8.86	0.64
DBP final (mmHg)	81.41 ± 9.37	79.15 ± 7.66	0.05
Dyspnea baseline (6-20 grade)	6.47 ± 0.86	6.15 ± 0.36	0.07
Dyspnea final (6-20 grade)	11.15 ± 2.11	11.85 ± 2.39	0.20
Leg fatigue baseline (1–10 grade)	0.21 ± 0.43	0.15 ± 0.42	0.16
Leg fatigue final (1–10 grade)	2.59 ± 1.12	3.34 ± 1.52	0.007*

Values are presented as mean ± standard deviation. 6MWD, 6-minute walk distance; 2MST, 2-minutes step test; HR, Heart rate; bpm: beats per minute; SpO_2, Oxygen saturation; SBP, systolic blood pressure; DBP, diastolic blood pressure. *p<0.05, statistically significant

Table 3. Relationships of 6MWT and 2MST with demographic parameters and muscle strength in mild-post-COVID-19 individuals

Variables	Correlation coefficient	6MWD (m)	2MST (no.)
2MST (no.)	r	0.350	
	p-value	0.043*	
Age (years)	r	0.098	-0.007
	p-value	0.581	0.967
Height (cm)	r	0.182	-0.140
	p-value	0.302	0.429
Weight (kg)	r	0.079	-0.140
	p-value	0.658	0.430
Quadricep strength (kg)	r	0.395	0.372
	p-value	0.021*	0.030*
Grip strength (kg)	r	0.250	0.091
	p-value	0.153	0.611

2MST, two minutes step test; 6MWD, six-minute walk distance; kg, kilogram; cm, centimeter; *p<0.05, statistically significant

Table 3 shows the relationships between the 6MWT and 2MST and various demographic and strength parameters in mild post-COVID-19 individuals. A significant positive correlation was found between the 6MWD and 2MST ($r = 0.350$, $p = 0.043$). Both the 6MWD and 2MST showed significant positive correlations with quadriceps strength (6MWD: $r = 0.395$, $p = 0.02$; 2MST: $r = 0.372$, $p = 0.03$). However, no significant correlations were found between the tests and age, height, or weight ($p > 0.05$). Similarly, grip strength did not show significant relationships with either test ($p > 0.05$).

Discussion

This study aimed to compare the physical capacity of young adults recovering from COVID-19 using 6MWT and 2MST, with a focus on cardiovascular responses, demographics, and muscle strength. Results indicated that the 6MWT significantly increased heart rate and leg fatigue, while the 2MST caused a notable rise in systolic blood pressure. Both tests were found to be correlated with quadriceps strength, highlighting their effectiveness in assessing physical function in post-acute COVID-19 recovery. These findings suggest that both tests can be valuable tools in guiding rehabilitation interventions and supporting functional recovery in this population.

The functional capacity measures, including the 6MWD, 2MST, quadriceps strength, and hand grip strength, provide insight into the participants' cardiovascular and muscular performance. The 6MWD (577.76 ± 29.02 meters) and 2MST (115.76 ± 13.44 repetitions) indicate good aerobic capacity and muscular endurance, as these values fall within the typical range for healthy young adults (Poh et al., 2006; Vaish et al., 2013). However, it is important to note that even among those with mild COVID-19, there may still be subtle, lingering deficits in muscular strength and aerobic performance, as shown by the lower quadriceps strength (20.31 ± 4.85 kg) and hand grip strength (22.83 ± 7.26 kg) when compared to non-infected peers (Tantibhaedhyangkul et al., 2020; Wang et al., 2018). This finding highlights the need for targeted rehabilitation strategies for individuals recovering from COVID-19 to restore full functional capacity.

Our study found that the 6MWT induced greater cardiovascular demand and muscular strain, as reflected by increased heart rate and leg fatigue following the test. These results are consistent with previous research, including studies by Reychler et al. (Reychler et al., 2018) and Troosters et al. (Troosters et al., 2002), which reported similar heart rate increases following the 6MWT. The increased cardiovascular response in the 6MWT can be attributed to the continuous movement and sustained weight-bearing nature of the test, both of which demand higher oxygen consumption and stimulate the cardiovascular system (Shephard et al., 1976). The significant leg fatigue observed post-test highlights the engagement of the quadriceps and lower limb muscles, underscoring the 6MWT's effectiveness in assessing both cardiovascular and muscular endurance. However, contrary to prior research, leg fatigue was notably higher after the 2MST than the 6MWT in patients with heart failure (Węgrzynowska-Teodorczyk et al., 2016) and older adults (Poncumhak et al., 2023; Srithawong et al., 2022).

The 2MST, though shorter in duration, led to significantly higher systolic blood pressure, pointing to a more intense, immediate response in terms of blood pressure regulation. The 2MST involves repetitive stepping at a fixed height and self-paced speed, focusing on lower-body muscles. Muscle contractions during the 2MST enhance venous return, increasing cardiovascular load. This muscle pump effect pushes more blood back to the heart, intensifying cardiovascular demands and leading to a greater rise in blood pressure compared to walking tests (Casey & Hart, 2008; Fisher & Secher, 2019). The biomechanics of the 2MST, requiring greater lower-body strength, coordination, and longer periods of single-leg balance, contribute to its higher physiological demands compared to the 6MWT (Beutner et al., 2015; Zhao & Chung, 2016). This discrepancy underscores the need for further investigation to better understand the comparative effects of these tests on muscular endurance and cardiovascular response.

These results show that the cardiovascular response differs between the 6MWT and 2MST. The 6MWT may better reflect sustained cardiovascular endurance, while the 2MST is more suited for short-term, high-intensity effort. Both tests are valuable for assessing post-COVID-19 recovery, with the 6MWT focusing on aerobic capacity and the 2MST on blood pressure regulation during exertion. Participants rated both tests below an RPE of 12, indicating low to moderate intensity. With RPE 12-13 correlating to 40-59 % VO_2 max (Medicine, 2013), both tests can be considered submaximal assessments, useful for monitoring recovery without overexertion

In young mild-post-COVID-19 individuals, the relationships between the 6MWT, 2MST, demographic parameters, and muscle strength reflect important insights into functional capacity. A significant positive correlation between the 6MWD and 2MST ($r = 0.350$, $p = 0.043$) suggests that both tests can be used interchangeably to assess functional performance in this population. This finding is

consistent with previous studies that have demonstrated the 2MST as an effective alternative to the 6MWT in assessing functional capacity, particularly in populations with mobility restrictions or post-illness recovery (Braghieri et al., 2021; Chow et al., 2023; Ishigaki et al., 2024) The 6MWT and 2MST assess different aspects of exercise capacity, but both demonstrate significant correlations with muscle strength. In our study, both the 2MST and 6MWD showed similar associations with quadriceps strength. These findings align with previous research that emphasizes the critical role of lower limb strength in functional performance, as stronger quadriceps are associated with better endurance and mobility (Poncumhak et al., 2023; Srithawong et al., 2022; Węgrzynowska-Teodorczyk et al., 2016) The lack of significant correlations with age, height, weight, and grip strength suggests that these factors might have less influence on functional outcomes in young, mild-post-COVID-19 individuals compared to more direct measures of lower body strength. This finding contrasts with studies on older populations, where weight and grip strength are often more strongly correlated with functional mobility (Kovarik et al., 2017; Kyomoto et al., 2019; Zhang et al., 2017). These results emphasize the importance of lower limb strength in functional performance in young individuals recovering from mild COVID-19. Future interventions may focus on strength-building exercises for the lower limbs to enhance recovery and prevent functional decline.

This study has several limitations. It primarily focuses on young adults with mild post-COVID-19 symptoms, limiting its relevance to more severe cases or older populations. The lack of long-term follow-up restricts the understanding of how physical function changes over time. Additionally, the study does not assess maximal oxygen consumption (VO2 max), which would provide a more precise evaluation of cardiorespiratory fitness. Future research should include more diverse populations, longer follow-up periods, and direct measurements of VO_2 max to better assess post-COVID-19 recovery.

Conclusions

The 6MWT resulted in increased heart rate and leg fatigue, while the 2MST led to a rise in systolic blood pressure post-test. Both tests were positively correlated with quadriceps strength, highlighting their utility in assessing and guiding recovery in post-acute COVID-19 patients.

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Conflict of Interest

The researchers claim no conflicts of interest.

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Оцінка впливу COVID-19 на функціональну здатність організму молодого дорослого населення: Порівняльний аналіз щодо застосування тесту з ходьби та степ-тесту у визначенні рівня фізичної витривалості

Патчарія Ампут[1ACD], Арунрат Срітхавонг[1ABCD], Сінтхупорн Махаран[1ADE], Путтіпонг Понкумхак[1ABCD], Пачарін Фромпао[1CD], Еакарач Вонгсая[1CD], Тічанон Промсрісук[1ABCD], Сахачат Ауеінгсак[2ACD]

[1]Університет Пхаяо
[2]Християнський університет Таїланду

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

Реферат. Стаття: 8 с., 3 табл., 44 джерела.

Мета дослідження. Це дослідження мало на меті за допомогою тесту 6-хвилинної ходьби (6ХХТ) та 2-хвилинного степ-тесту (2ХСТ) оцінити та порівняти функціональну здатність організму молодого дорослого населення, що проходить період відновлення після COVID-19, акцентуючи увагу на параметрах серцево-судинної системи, а також дослідити кореляції між зазначеними тестами, демографічними факторами та м'язовою силою.

Матеріали та методи. Проведено поперечне дослідження за участю 34 молодих учасників (середній вік: 20,62 років, 88,24 % жінок), які мали легкі симптоми після перенесеного COVID-19. За допомогою тестів 6ХХТ і 2ХСТ оцінювали показники м'язової сили (сила хвату і сила чотириголового м'яза стегна), а також функціональну здатність, причому порядок проведення тестів визначався за методом випадкового відбору. Вимірювання показників гемодинамічних реакцій, втоми та задишки проводилось перед початком та після завершення обох тестів. Для порівняння параметрів серцево-судинної системи та втоми в нижніх кінцівках між 6ХХТ та 2ХСТ використовували метод t-критеріїв для парних вибірок. За коефіцієнтом кореляції Пірсона оцінювали взаємозв'язок між обома тестами, демографічними даними та м'язовою силою.

Результати. В рамках дослідження виявлено збільшення частоти серцевих скорочень і втоми в нижніх кінцівках після виконання 6ХХТ порівняно з 2ХСТ, тоді як після проведення 2ХСТ спостерігалося підвищення систолічного артеріального тиску порівняно з 6ХХТ. За результатами 6ХХТ встановлено значну позитивну кореляцію з 2ХСТ ($r = 0,350$, $p = 0,043$). Крім того, показник сили чотириголового м'яза стегна позитивно корелював як з 6ХХТ ($r = 0,372$, $p = 0,030$), так і з 2ХСТ ($r = 0,395$, $p = 0,021$).

Висновки. Результати цього дослідження свідчать про ефективність застосування 6ХХТ та 2ХСТ щодо оцінки функціональної здатності організму у молодих осіб, що проходять період відновлення після COVID-19, демонструючи чіткі фізіологічні реакції. До того ж, сила чотириголового м'яза стегна корелює з обома тестами, що підкреслює важливість показника м'язової сили у процесі одужання.

Ключові слова: COVID-19, тести для оцінки стану фізичної підготовленості, функціональна підготовленість, кардіореспіраторна витривалість.

Information about the authors:

Amput, Patchareeya: patchareeya.am@up.ac.th; https://orcid.org/0000-0002-2484-2996; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Srithawong, Arunrat: arunrat.sr@up.ac.th; https://orcid.org/0000-0002-7647-5657; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Maharan, Sinthuporn: Sinthuporn.ma@up.ac.th; https://orcid.org/0000-0001-8230-0821; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Poncumhak, Puttipong: puttipong.po@up.ac.th; https://orcid.org/0000-0002-7788-7151; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Phrompao, Patcharin: patcharin.ph@up.ac.th; https://orcid.org/0000-0001-8020-7033; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Wongsaya, Eakarach: wongsaya.ea@up.ac.th; https://orcid.org/0000-0003-4314-9211; Department of Physical Therapy, School of Allied Health Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Promsrisuk, Tichanon: tichanon.pr@up.ac.th; https://orcid.org/0000-0001-8523-2633; Division of Physiology, School of Medical Sciences, University of Phayao, 19 Moo 2 Maeka, Phahonyothin Road, Mueang Phayao district, Phayao 56000, Thailand.

Aueyingsak, Sahachat: Audjand@gmail.com; https://orcid.org/0000-0002-5761-149X; Department of Physical Therapy, College of Health Sciences, Christian University of Thailand, 144 Don Yai Hom, Mueang Nakhon Pathom District, Nakhon Pathom 73000, Thailand.

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Social Representations of the Curriculum in Physical Education Teachers: A Multi-Method Analysis regarding Teachers from Copacabana, Colombia

Roger Alexander Gonzalez Ramirez[1ABCD] and Enoc Valentin Gonzalez Palacio[2ABCD]

[1]University of San Buenaventura
[2]University of Antioquia

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

Corresponding Author: Roger Alexander Gonzalez Ramirez, e-mail: nisaro15@gmail.com
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Abstract

Objectives. This study aimed to provide a specific analysis of social representations on the curriculum in physical education teachers.

Materials and methods. The study focuses on a sample of 25 physical education teachers from Copacabana, Antioquia, using a multi-method approach with a predominance of grounded theory. Data were collected through in-depth interviews, sociodemographic surveys, and natural semantic networks.

Results. Qualitative analysis using ATLAS.ti revealed four emerging categories in this group: dynamic and situated curriculum, curriculum for comprehensive training, flexible and contextualized curriculum, and prescriptive curriculum. Quantitative analysis identified a central core of representation composed of concepts such as planning, instructions, and education. The results indicate that physical education teachers conceive the curriculum in a multidimensional way, reflecting the particularities of their discipline. A tension is observed between adherence to prescriptive curricular structures and the need for flexibility to address the specific demands of physical education.

Conclusions. The study concludes that these representations are strongly influenced by the practical context of teaching physical education, suggesting the need for curricular approaches adapted to this area.

Keywords: social representations, curriculum, physical education, planning, comprehensive training.

Introduction

The epistemological and cultural elements that determine the purposes associated with training are embedded in the school curriculum; its analysis favors an approach to school culture and the actors that give life to the school, hence problematizing the curriculum constitutes a current task for the institutionalIty.

To do so, this exercise takes as its axis the concept of social representations by Serge Moscovici (1979), representations contribute to the understanding of complex and situated phenomena such as the curriculum. Additionally, they constitute an expeditious path to return to people and their daily practices as a source of conceptual elaboration. Social representations allow us to understand the knowledge of communities from what they do in an unprepared way; their voices and actions are the reference for the concretion of metacognitive processes.

This characteristic of social representations brings it closer to the curriculum, facilitating the reconstruction of the concept and its relations with more complex elaborations such as didactics or pedagogy. Bourdieu (1997) points out that the conceptual elements that add up to the capitals of a people are built in social interaction, which underlines the importance of their study in the spaces and routines of the school, a natural space for the construction of the curriculum.

The research takes as a reference the approaches of Jean-Claude Abric (2001) on the structure of social representations, postulating that all representation is organized around a central core and a peripheral system. According to Abric (2001) "the central core is the fundamental element of the representation since it determines both the meaning and the organization of the representation" (p. 20).

On the other hand, the peripheral system, which surrounds the central core, is made up of more flexible and dy-

namic elements. These peripheral elements "allow individual adaptations of the representation" (Abric, 2001, p. 23) and act as a frame of reference that contributes to the understanding of the phenomenon, its structure, connections, and meanings; as Lo Monaco et al. (2013) point out, "peripheral elements are much more sensitive to the immediate context" (p. 5), which allows the social representation to adapt to specific situations and to account for the trends and perspectives that make up the representation as a whole.

This reflection on the contexts is shared with the curriculum, since from critical theories it is assumed as a cultural and emancipatory construction (Grundy, 1987). Fernández (2016) points out that what happens with the curriculum, its movements and transformations go through the practices associated with everyday school life and the social representations developed there for the purpose of teaching.

The review of the background reveals a growing interest in understanding how teachers construct the curriculum in their daily practice. For Gómez and Velasco (2017), teachers' curricular practices depend on multiple factors, including institutional learning expectations and community aspects; along the same lines, Fernández (2016) underlines the importance of understanding the curriculum as a historical and social construction. This is complemented by what Giraldo et al. (2019) propose, who point out the diversity of approaches and the lack of conceptual clarity in curricular reflection in the West. It highlights that for some authors such as Labrador (2020), teachers incorporated devices and strategies into pedagogical practice, which can contribute to the understanding of what happens in the classroom and the associated knowledge. Finally, for other researchers such as Aguirre (2017), it is essential that reflection on the curriculum goes beyond traditional disciplines and focuses on fields that have an impact on other aspects of schooling such as corporality.

Regarding the link between social representations and curriculum, for authors such as Jesús Pérez (2016), the curriculum reflects the knowledge and experiences of the people, hence its study should focus on the people who create it; for Fernández Menor (2020), given the historical nature of the curriculum, it is essential to direct the instruments beyond the conceptual aspects and cross-reference them with elements such as experience. Cadavid (2019) proposes a curricular construction that goes beyond the nomination of content and integrates school subjects in its elaboration, an aspect endorsed by Ortega Rodríguez (2020), who points out that given the dialogical nature of the curriculum and the way it influences the development of the training project, it is necessary to return to those who problematize it in the classroom to favor its analysis and understanding.

This research sought to expand knowledge about how educators name and make the curriculum possible. To do so, the following question was raised: What are the social representations that teachers in the municipality of Copacabana have constructed in relation to the curriculum and the relationships they establish from them with their classroom practice?

Materials and Methods

Sample Selection

The study sample consisted of 25 physical education teachers intentionally selected from seven educational institutions in the municipality of Copacabana. The majority of the teachers surveyed were men (60 %), the average age was 36.4 years (SD = 11.3). The age distribution shows a wide range, from 25 to 59 years. As regards the level of education, a trend towards advanced professional qualifications was observed. 40% of the participants had postgraduate studies (28% with a specialization and 12 % with a master's degree), while the remaining 60 % had undergraduate education. 70 % of the teachers worked in urban areas, and the vast majority worked at the basic secondary level.

Information Gathering Techniques

Three data collection techniques were used: in-depth interviews, sociodemographic surveys, and natural semantic networks. The in-depth interview, following Galeano (2007), allowed the teachers' narratives and experiences about the curriculum to be captured. The sociodemographic survey provided contextual information about the participants, while natural semantic networks, as proposed by Velásquez and Córdoba (2018), facilitated the identification of the conceptual associations and relationships that teachers establish around the curriculum.

Design and Procedures

A multi-method approach with a predominance of grounded theory, as proposed by Creswell and Guetterman (2019), was adopted to capture the complexity of social representations about the curriculum. In complementary terms, a descriptive non-experimental quantitative study was used. The data collection process was carried out between June 2022 and June 2023, allowing to capture the current dynamics in the educational field. Individual interviews were conducted, surveys were applied, and the natural semantic network technique was implemented in group sessions.

The qualitative analysis was carried out using Atlas Ti v24 software, following the open, axial and selective coding procedures proposed by Strauss and Corbin (2002). This process allowed us to identify emerging categories, establish relationships between them and build a substantive theory on the social representations of the curriculum. A constant iterative and comparative analysis was carried out until theoretical saturation was reached.

Statistical Analysis

For the quantitative analysis, Statistical Analysis in Microsoft Excel and SPSS 29 was used, carrying out a descriptive and semantic network analysis (González, 2019, p. 48). The statistical profile of the defining words expressed by teachers in relation to the curriculum was established, and the representational structure was determined. The method proposed by González (2019) was applied to identify the central core of the social representation, establishing a cutoff when a word presented a semantic distance of 5 % or more from the main defining word.

Results

The results are grouped into two sections. The first refers to the elements associated with qualitative instruments (in-depth interviews), and the second section presents

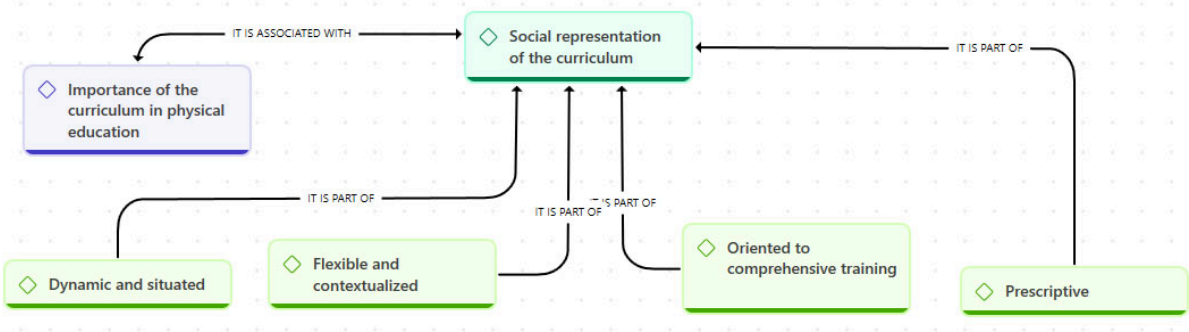

Fig. 1. Categorical network associated with the curriculum

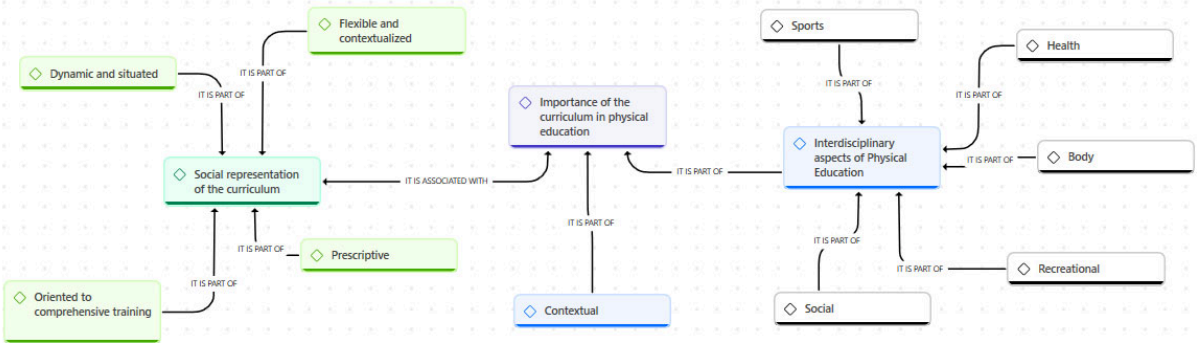

Fig. 2. Axial categories that refer to the curriculum

the findings in relation to natural semantic networks and representational structure.

Figure 1 presents the categorical structure emerging from the qualitative analysis of social representations. This analysis reveals four axial categories: flexible and contextualized curriculum, dynamic and situated, oriented to comprehensive training, and prescriptive. Additionally, aspects related to the importance of the curriculum in physical education and its disciplinary dimension are identified.

It is notable how, for the participants, elements such as context, health, sport, body, social and recreation shape their conceptions of the discipline and the associated curriculum. This finding agrees with that indicated by Baena et al. (2023), who identify these elements as key factors in the construction of the competencies of the area, those that teachers incorporate into their pedagogical practice and in the curricular design. This interrelation between teaching experiences and the specific disciplinary components of physical education underlines the complexity of social representations in this field.

The social representations of the curriculum were analyzed through the defining words and their metrics: frequency, order, semantic weight (M), semantic distance (FMG) and semantic percentage. These elements reveal the structure of the representation.

Figure 2 presents a structure that reflects the semantic distances between the defining words that make up the central core of the social representation of the curriculum in physical education teachers. This core is composed of 22 lexical units, which are positioned at the center of the hegemonic representation. The prominence of terms such as "Planning", "Instructions" and "Education" suggests a vision of the curriculum strongly linked to organizational and pedagogical aspects. This is in line with what González-Hernández et al. (2022) point out, who highlight that "training in physical education must integrate pedagogical and organizational aspects that respond to the current demands of the educational and sports field" (p. 5).

The hegemonic structure is complemented by peripheral elements that, although they have less semantic weight, are crucial to understanding the complexity and dynamism that the analysis has revealed as underlying the curricular study.

Fig. 3. Semantic distance from the hegemonic social representation of the curriculum

Table 1. Defining words associated with the social representation of the curriculum

Words	Frequency	Order	M value	FMG	%M	%RS	RS
Planning	5	22	110	100.0	12.7		
Instructions	5	19	95	86.4	10.9		
Education	5	16	80	72.7	9.2		
Physical activity	4	15	60	54.5	6.9		
Pei	5	12	60	54.5	6.9		
Sport	4	14	56	50.9	6.5		
Teaching	4	13	52	47.3	6.0		
Competencies	4	12	48	43.6	5.5		
Learning	3	15	45	40.9	5.2		
Integration	3	14	42	38.2	4.8		
Strategies	2	8	16	14.5	1.8	90.7	RSH
Assessment	3	5	15	13.6	1.7		
Coordination	2	7	14	12.7	1.6		
Teaching	2	7	14	12.7	1.6		
Scheme	2	7	14	12.7	1.6		
Goals	2	7	14	12.7	1.6		
Knowledge	2	6	12	10.9	1.4		
Subjects	2	5	10	9.1	1.2		
Equipment	2	5	10	9.1	1.2		
Training	2	4	8	7.3	0.9		
Context	2	3	6	5.5	0.7		
Guide	2	3	6	5.5	0.7		

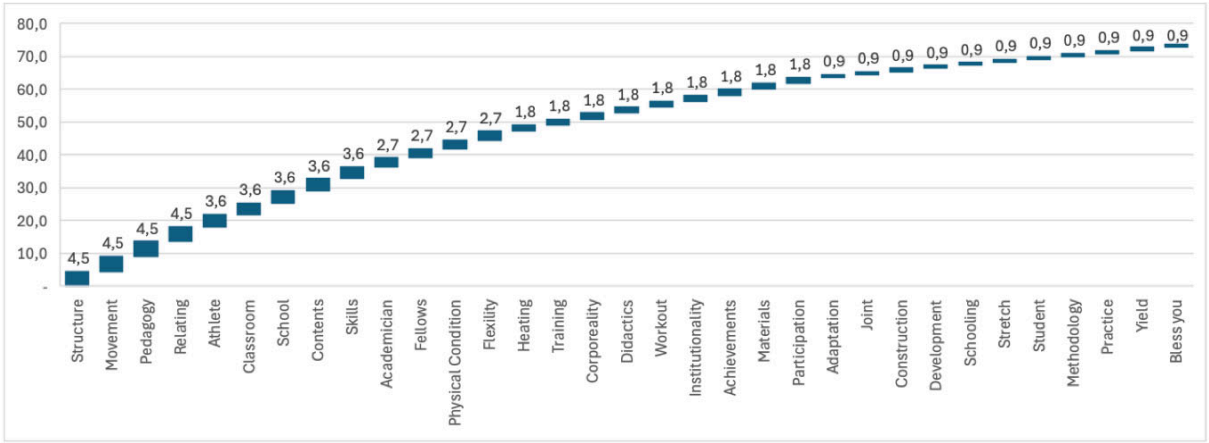

Fig. 4. Semantic distance of the peripheral social representation of the curriculum

The graph reveals a series of concepts that broaden the understanding of the curriculum in the field of physical education. It highlights the presence of terms such as "structure", "movement", "pedagogy" and "referents," which suggest a vision of the curriculum that goes beyond the merely instrumental. As Molina Neto (2023) points out, "physical education is not limited to physical activity, but encompasses comprehensive human development, including pedagogical, social and cultural aspects" (p. 3). This perspective is reflected in the inclusion of concepts such as "skills", "flexibility" and "warm-up".

Discussion

The qualitative results showed four emerging categories. Below are some considerations linked to the testimonies of

the participants and the considerations that the study raises as a result of the analysis.

Dynamic and Situated Curriculum in Physical Education

The curriculum in the field of physical education is revealed as a multidimensional construction, this is made evident when the participants point out: "The curriculum allows the complexity of the field of performance of the physical educator to be made visible, allowing issues such as locomotion, nutrition, calisthenics, and sports to be put on the classroom stage" (Ent-6). This statement underlines the capacity of the curriculum to develop formative practices that accommodate the complexity of the area and the different elements that make up the corporal development in schoolchildren. In addition, another participant emphasizes the collaborative nature of the curricular construction by stating that "The curriculum is an agreement around which to learn, its elaboration is based on the knowledge of the teacher and the school formative project" (Ent-8). This conception highlights the importance of a pertinent and significant curriculum that starts from the knowledge of teachers and the recognition of the context.

This understanding of the curriculum places the teacher as a key actor in the construction of pedagogical knowledge and its development in the classroom. Cardona Marín et al. (2024) postulate that the curricular structure in physical education should be a reflection of the specific competencies that learners are expected to use to insert themselves into cultural dynamics.

Flexible and Contextualized Curriculum

Participants associate the curriculum with a construction capable of adapting to the contemporary demands of the discipline and the interests of students. This is evidenced in a testimony that states: "The curriculum is the bridge between theory and practice, in the case of physical education it allows us to understand biologically how the body works, its possibilities and limitations" (Int-5). This curricular allusion underlines the integrative function of the curriculum, which articulates theoretical knowledge with practical experience, facilitating a deep understanding of corporality.

Regarding this relationship, Rojo-Ramos et al. (2024) point out that the Physical Education curriculum needs to adapt to technological and social changes in order to effectively meet the needs of students. This statement underlines the importance of a dynamic curricular design, capable of incorporating pedagogical innovations that enrich the learning experience.

Curriculum for comprehensive training

The curriculum in the testimonies is presented as a construction capable of adapting to the changing needs of the educational environment and of the students. One of the participants states: "The curriculum allows the educator to put their knowledge around how the body works, based on what students and people do on a daily basis to get from one place to another, play, breathe" (Int-7).

In this sense, Balcázar et al. (2024) point out that physical education must go beyond the physical and promote a development that involves the daily life of subjects and what they do in their lives. That is, a curriculum that encourages training that addresses elements such as identity, citizenship, and culture. Such a curriculum becomes a means for the training of individuals capable of understanding and using their corporeality in relation to the sociocultural spaces and practices in which they live.

Prescriptive Curriculum

This conception of the curriculum is based on the recognition of the regulatory and institutional documents that are intended for teaching. One of the participants points out that" The school curriculum is based on legal references and allows the teacher to lead his students in the construction of the expected competencies for the level of training" (Ent-13). This vision highlights the normative nature of the curriculum as a vehicle for transmitting social references, while recognizing its role in the integral formation of the individual.

The notion of prescriptive curriculum is based on the need to provide a coherent and well-founded structure for educational practice. In this regard, Stahringer and Carbajal (2024) point out that the curriculum calls for a solid disciplinary foundation and a reflection on what happens in the classroom; prescription is the starting point. However, its development is conditioned by the knowledge, experiences, and questions inherent to pedagogical practice.

Structure of the representation

The proximity of "Physical Activity" and "Sport" to the reference values of the representational core highlights disciplinary specificity, while the presence of "PEI" indicates the importance of the institutional framework. Concepts such as "Competencies", "Learning" and "Integration" reflect a contemporary educational approach. This configuration suggests a representation that balances technical aspects of the discipline with broader educational considerations; for Pérez-Pueyo et al. (2022) "the new Physical Education curriculum must promote comprehensive training, which not only develops motor skills, but also socio-emotional and cognitive skills" (p. 78).

The peripheral elements of social representation are organized around the central core. These elements can be categorized mainly into three aspects: the structure and form of the class, the curricular components related to the formative and pedagogical aspects, and the disciplinary issues specific to the area of physical education, such as movement and basic motor skills. This configuration suggests that, although the structure of social representation tends to maintain a certain stability, it is susceptible to variations due to the inherent dynamism of the context and the flexible nature of the curriculum. These variations can manifest themselves in relation to teaching practice, teacher training and the educational environment.

Conclusions

The trend toward standardization, reflected in concepts such as "planning" and "instructions," may conflict with the dynamic nature of the field of physical education. This raises the need for more flexible curricular approaches that

balance the requirements of the area with the particularities of the context, school actors, and discipline.

The identified representations reflect a tension between tradition and innovation. Terms such as "sport" and "physical activity" coexist with emerging elements such as "integration" and "skills", indicating an evolution towards more holistic approaches. This duality underlines the need for a continuous dialogue between established practices and new pedagogical trends.

The presence of elements such as "adaptation" and "flexibility" indicates an awareness of the need for ongoing training. It is important to implement professional development programs that promote ongoing training in technical knowledge, pedagogical aspects and recognition of the context.

Another important issue is the urgent need for curricular models that favor recognition of the contextual elements of the territories, their inhabitants and social dynamics. The curriculum must allow for the conjuring up in a single practice disciplinary, cultural and historical issues; it is about consolidating a proposal that starts from the disciplines, while recognizing the value of culture, the knowledge of people and the principle of formability that underlies any school process.

Conflict of Interest

The researchers claim no conflicts of interest.

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Соціальні репрезентації викладачів фізичного виховання щодо навчальної програми: Мультиметодичний аналіз стосовно викладачів з Копакабани, Колумбія

Роджер Александр Гонзалез Рамірез[1ABCD], Енок Валентин Гонзалез Паласіо[2ABCD]

[1]Університет Святого Бонавентури, Медельїн
[2]Антіокійський університет

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

Реферат. Стаття: 7 с., 1 табл., 4 рис., 27 джерел.

Мета дослідження. Мета цього дослідження полягала в здійсненні специфічного аналізу соціальних репрезентацій викладачів фізичного виховання щодо навчальної програми.

Матеріали та методи. Дослідження фокусується на вивченні вибірки із 25 викладачів фізичного виховання з Копакабани, Антіокія, із застосуванням мультиметодичного підходу, в якому перевага надається обґрунтованій теорії. Збір даних здійснювався за допомогою проведення глибинних інтерв'ю, соціодемографічних опитувань та природних семантичних мереж.

Результати. За результатами якісного аналізу із використанням програмного забезпечення ATLAS.ti виявлено чотири нові категорії в цій групі: динамічна та ситуативна навчальна програма, навчальна програма для комплексної підготовки, гнучка та контекстуалізована навчальна програма, а також прескриптивна навчальна програма. Кількісний аналіз визначив центральне ядро репрезентації, що складається з таких концептів, як-от планування, інструкції та освіта. Результати дослідження свідчать про те, що викладачі фізичного виховання розуміють навчальну програму у багатовимірний спосіб, що відображає специфіку їхньої дисципліни. Спостерігається протиріччя між дотриманням прескриптивних навчальних структур і необхідністю гнучкості задля задоволення специфічних вимог фізичного виховання.

Висновки. Згідно з результатами дослідження встановлено, що зазначені репрезентації значною мірою залежать від практичного контексту викладання фізичного виховання, що вказує на необхідність адаптації навчальних підходів до цієї галузі.

Ключові слова: соціальні репрезентації, навчальна програма, фізичне виховання, планування, комплексна підготовка.

Information about the authors:

González Ramírez, Roger Alexander: nisaro15@gmail.com; https://orcid.org/0000-0002-8090-5584; Universidad de San Buenaventura, Medellín, Carrera 56C N° 51-110 Centro - Medellín 5145600, Medellín, Antioquia, Colombia.

González Palacio, Enoc Valentín: enoc.gonzalez@udea.edu.co; https://orcid.org/0000-0001-7708-7886; Universidad de Antioquia, Cra. 75 No. 65-87, Bloque 45 Ciudadela Robledo, Medellín, Antioquia, Colombia.

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Original Scientific Article

The Effect of Endurance Training on Blood Lactate Concentration and Anaerobic Threshold in Bangladeshi Female Handball Athletes

Sharmin Akter Shanta[1ABCDE] and Ajita[1ABCDE]

[1]Punjabi University

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

Corresponding Author: Sharmin Akter Shanta, e-mail: shantaakhter22@gmail.com
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Abstract

Background. Endurance training has an essential role in improving the aerobic capacity and postponing the onset of exhaustion that can be beneficial to enhancing the performance. Handball involves both aerobic and anaerobic energy systems in the human body. Therefore, it becomes crucial to comprehend how training influences physiological variables such as anaerobic threshold and blood lactate concentration.

Objectives. The objective of this study was to examine the effect of an endurance training program on anaerobic threshold and blood lactate concentration in Bangladeshi female handball players.

Materials and methods. A total of sixty-four female athletes were selected using a purposive random sampling technique. The participants were randomly divided into two groups: 32 in the experimental group and 32 in the control group. A blood lactate analyzer, pulse oximeter, and treadmill test according to the Bruce protocol were used to assess blood lactate concentration, anaerobic threshold, resting heart rate, and maximum heart rate.

Results. The study observed a significant improvement in the experimental group, including a reduction in resting blood lactate concentration from 1.72 ± 0.15 mmol/L to 1.42 ± 0.12 mmol/L at the post-training phase. Additionally, there was an increase in onset of blood lactate accumulation from 4.51 ± 0.26 mmol/L to 4.73 ± 0.15 mmol/L, and an increase in speed at lactate threshold from 7.0 ± 0.0 km/h to 7.49 ± 0.19 km/h. It was also noted a considerable enhancement in the control group for variables such as resting heart rate, maximum heart rate, resting blood lactate concentration, and peak lactate concentration due to regular handball participation. Cohen's d was calculated to determine the effect size of endurance training. An independent t-test also revealed substantial differences between the experimental and control groups ($p < 0.05$).

Conclusions. The findings of this study indicate a significant effect of endurance training on the anaerobic threshold and blood lactate concentration in Bangladeshi female handball players.

Keywords: endurance training, blood lactate concentration, anaerobic threshold, onset of blood lactate accumulation, female handball players.

Introduction

Physical training is an integral component of athletic performance, particularly in sports that require a combination of aerobic endurance and anaerobic capacity for success (Reza et al., 2024). In handball, players engage in high-intensity intermittent efforts with short recovery breaks, making it essential for athletes to perform near or at their anaerobic threshold to excel. Blood lactate accumulation, commonly referred to as the onset of blood lactate accumulation (OBLA), is a key marker of the anaerobic threshold and serves as an important determinant of endurance capacity. It correlates with an athlete's ability to sustain prolonged high-intensity exercise without experiencing fatigue (Brooks, 1985; Faude et al., 2009).

Endurance training has been well-documented to enhance anaerobic capacity while reducing blood lactate levels during both submaximal and maximal exercise, leading to improved performance (Soyal et al., 2017; Sales et al., 2019). Monitoring blood lactate concentration across different phases of exercise testing helps identify the limits of each phase, allowing for the design of more effective training programs. Both lactate threshold and OBLA are highly responsive to endurance training. Researcher Ghosh (2004) argues that while lactate production decreases with training at a given

work rate, the lactate threshold occurs later, enabling endurance athletes to sustain higher intensities before the onset of exhaustion.

Ball players require a balance of strength and power, which are crucial for both the aerobic and anaerobic components needed to execute powerful movements (Rahman & Sharma, 2023). Handball players require a balance of aerobic and anaerobic components to execute powerful actions while maintaining high anaerobic metabolism. Enhancing lactate clearance and improving the anaerobic threshold can significantly impact performance. Research shows that aerobic endurance training increases parameters such as lactate threshold speed, resting heart rate, and maximal heart rate, all of which are essential for sustaining prolonged performance (Denis et al., 1984; Poole et al., 2021).

Sustaining repeated high-intensity actions and recovering quickly are essential for handball players, as this helps minimize the risk of injury in athletes engaged in high-intensity sports (Islam et al., 2024). Effective performance depends on the ability to draw energy from both oxidative metabolism and anaerobic glycolysis, which requires a strong endurance base and the ability to resist fatigue, as evidenced by improvements in anaerobic threshold and blood lactate dynamics (Bishop et al., 2013; Meckel et al., 2009). The anaerobic threshold, defined as the exercise intensity at which lactate begins to accumulate in the blood, is a key performance parameter in endurance sports. Regular training above the lactate threshold helps increase the threshold, enabling athletes to perform more work before fatigue sets in, ultimately improving overall performance (Svedahl & MacIntosh, 2003).

In handball, where there is frequent alternation between aerobic and anaerobic energy systems, endurance training increases the anaerobic threshold and reduces blood lactate accumulation (Jacobs et al., 1986). Investigating the effects of endurance training on anaerobic threshold and blood lactate concentration in Bangladeshi female handball players offers valuable insights into optimizing training regimens. Despite the popularity of handball worldwide, there is limited scientific research on the physiological effects of specific training programs on South Asian handball players, particularly female athletes. This knowledge is essential for athletes and coaches aiming to improve anaerobic thresholds and regulate lactate accumulation during competition (Gordon & Scott, 2020; Kuk & McMillan, 2017).

This study investigates how an 8-week endurance training program affects blood lactate concentrations and anaerobic threshold in Bangladeshi female handball players. It focuses on key physiological variables, including lactate threshold speed (LT speed), onset of blood lactate accumulation (OBLA), and lactate threshold heart rate (LTHR). By providing new insights into endurance training adaptations in this unique athletic population, the study contributes to the limited research on female athletes in Bangladesh. The findings are expected to reveal important changes in resting lactate levels, OBLA, and lactate threshold performance, offering valuable information on improving athletic conditioning and performance.

Materials and Methods

Study Participants

A total of sixty-four female handball players were purposively selected from the Kushtia District of Khulna Division, Bangladesh. The participants were randomly assigned to an experimental group (EG), which performed specific aerobic exercises for endurance, and a control group (CG), which did not participate in these exercises. Table 1 illustrates the detailed characteristics of the subjects, including age, height, weight, and BMI. Before the trial began, participants were thoroughly informed about the study, including its benefits and any potential risks, ensuring they could make an informed decision about participation. All potential participants underwent a comprehensive medical examination by an attending physician to confirm their eligibility. All volunteers were in good health and deemed capable of safely undertaking the training regimen.

The research followed the ethical principles of the Declaration of Helsinki, ensuring that ethical standards were upheld throughout the investigation. This compliance reflects the study's commitment to the ethical treatment and respect of all participants. The Helsinki Declaration (2004) outlines pathways through which endurance training improves lactate regulation and performance, aiding in the development of optimized conditioning programs for these populations.

Study Organization

This study employed an experimental methodology using a two-group pretest-posttest design. The treatment group consisted of thirty-two participants who underwent an eight-week targeted endurance training program (table 2). The control group also comprised thirty-two participants who did not undergo this training, serving as the comparison group.

Table 1. Participants characteristics (Mean ± SD)

Characteristics	EXP (n = 32)	CON (n = 32)
Age(years)	16.44 ± 1.97	15.50 ± 1.83
Height(cm)	158.89 ± 6.92	158.24 ± 5.85
Weight(kg)	54.19 ± 6.21	55.41 ± 10.96
BMI (kg/m2)	21.73 ± 1.86	22.15 ± 3.78

Note: EXP is the group that practices endurance training, and CON control group refers to the groups did not receive endurance training. Values are reported as mean measurement with standard deviation (SD) the variability within each group.

All parameters were measured according to the standard protocols adopted in our laboratory. Prior to the program, a pre-test was conducted to evaluate all parameters for both groups. Following the trial, both groups participated in a standardized handball training program, which included technical drills, tactical exercises, and match play, conducted six days a week for eight weeks. The experimental group also underwent additional weekly endurance training sessions focused on increasing anaerobic threshold and cardiovascular endurance. These sessions ranged from high-intensity interval training (HIIT) to steady-state runs, as well as detailed anaerobic capacity-building exercises.

These protocols ensured that participants were in optimal condition for the experimental procedures. This systematic approach was designed to minimize variability and maintain adherence to ethical guidelines and scientific rigor throughout the study.

Table 2. Eight-week endurance training schedule for female handball players

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1st week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 10-15 min slow continuous run. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 2 laps handball field run at 70 % HR, 2-3 min rest between sets. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 2 sets of 3x30 sec reps with 30-sec break at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 20 min easy, off-road running. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
2nd week	Endurance: 10 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Endurance: 3 sets of field run at 60-70 % HR, 2-3 min rest between sets. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Pyramid training (20m, 40m, 60m, 80m, 120m) at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 20 min easy, off-road running. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
3rd week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 15-20 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 2 sets of 3x40m slow/fast handball field runs at 60-70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Pyramid training (20m, 40m, 60m, 80m, 120m) at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 20 min swimming or cycling. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
4th week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 15 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Pyramid training (10m, 30m, 50m, 80m, 110m) at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 3x45 sec reps with 60-sec break at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 20 min swimming or cycling. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
5th week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 20 min continuous run. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 3 laps handball field run at 70 % HR, 2-3 min rest between sets. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 2x30 sec reps with 30-sec break at 75 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 30 min easy, off-road running. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest

Table 2 (continued)

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6th week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 15 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 2 sets of 3x150m handball field runs at 75 % HR, 2-3 min rest between sets. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Circuit training (6 stations, 30 sec each) at 75 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 30 min off-road running or cycling. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
7th week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 20 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 3x20m slow/fast handball field runs at 60-70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Pyramid training (20m, 40m, 60m, 80m, 120m) at 70 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 30 min swimming or cycling. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest
8th week	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 20 min continuous run at moderate speed. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: Pyramid training (10m, 30m, 50m, 80m, 110m) at 75 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Rec. act.	Warm-up: Jogging 10 min; Dynamic exercises. Endurance: 3 sets of 3x60 sec reps with 60-sec break at 75 % HR. Skill practice: 20 min. Cool down: Limbering down and stretching (5 min).	Run: 30 min swimming or cycling. Dynamic exercises. Skill practice: 20 min. Lead-up: Recreational game (10 min).	Rec. act.	Rest

Treadmill Protocol

The anaerobic threshold was measured using an incremental treadmill test on a motorized treadmill (Cardiovit Ergo-Spiro CS 200, Schiller AG, Switzerland) under controlled conditions. After a 10-minute warm-up at 50 % heart rate reserve, the test began at 6 km/h, with speed increasing by 0.5 km/h every 2 minutes until exhaustion. The treadmill incline was set at 0 %. Heart rate was monitored continuously, and blood lactate concentration was measured periodically to assess the anaerobic threshold. The onset of blood lactate accumulation (OBLA) was recorded, with threshold heart rate or blood lactate concentration used to determine the lactate threshold (Vachon et al., 1999; Ghosh, 2010). This protocol was used to evaluate the exercise capacity of participants.

Blood Lactate Measurement

At the end of each stage, blood lactate concentrations were measured using a portable lactate analyzer (Lactate Scout 4, EKF Diagnostics). After cleansing the fingertip with alcohol and blotting the first drop of blood, a capillary blood sample was collected using a lancet. A drop of blood was placed on a test strip in the analyzer, providing results in mmol/L within 10 seconds. This process was repeated at each stage to monitor lactate levels during the treadmill test. The anaerobic threshold was determined by the point of a marked increase in blood lactate, typically at the onset of blood lactate accumulation (OBLA, 4 mmol/L).

Cardiovascular Parameters

Resting heart rate was measured using an Apple Watch and a pulse oximetry heart rate monitor, with participants seated at rest for 10 minutes. Maximum heart rate was recorded at the point of exhaustion during the graded treadmill test.

Statistical Analysis

SPSS version 23.0 (IBM Corp., Armonk, NY) was used to analyze the data. Descriptive statistics were computed for each measured variable, expressed as mean ± standard deviation. Independent t-tests were conducted to assess differences between the experimental and control groups, while paired t-tests compared pre- and post-training values within each group. Statistical significance was set at $p < 0.05$.

The effect size was determined using Cohen's d method, which evaluates the strength of the training effect after significant changes were identified.

Results

Table 3. Paired sample t-test (experimental group)

Variables	RL (mmol/L)		OBLA (4 mmol/L)		PL 8km/h(mmol/L)	
Group	EXP		EXP		EXP	
Test	pre	post	pre	post	pre	post
Mean	1.72	1.42	4.51	4.73	12.66	13.17
SD	.15	.12	.26	.15	.749	.74
t value	10.12		-3.874		116.44	
Sig.(2-tailed)	.000		.001		.000	

Note: RL: Resting Blood Lactate; OBLA: Onset of Blood Lactate Accumulation; PL: Peak Blood Lactate

Table 3 shows that statistically significant changes at the 0.05 confidence level were observed in all variables for the experimental group (EXP) using a paired t-test analysis of pre- and post-training measurements. Resting Blood Lactate (mmol/L) showed a notable reduction, with the mean decreasing from 1.72 ± 0.15 before training to 1.42 ± 0.12 afterward ($t = 10.12$, $p < 0.05$). Although the change in Onset of Blood Lactate Accumulation (OBLA, 4 mmol/L) was modest, the mean increased slightly from 4.51 ± 0.26 to 4.73 ± 0.15, which was statistically significant ($t = -3.874$, $p < 0.05$). For Peak Blood Lactate (mmol/L), there was a significant increase, with the mean rising from 12.66 ± 0.749 to 13.17 ± 0.74 ($t = 116.44$, $p < 0.05$). These findings indicate meaningful physiological adaptations following the training.

Table 4 shows that, at the 0.05 confidence level, the paired t-test analysis of the experimental group revealed statistically significant improvements in all variables between pre- and post-training measurements.Lactate Threshold Speed (km/h) increased from 7.0 ± 0.0 to 7.41 ± 0.19, with a t-value of 11.59 ($p < 0.05$). Lactate Threshold Heart Rate (LTHR, bpm) rose from 136.15 ± 5.86 to 154.00 ± 9.57, showing a t-value of 15.05 ($p < 0.05$). Resting Heart Rate (HRrest, bpm) decreased from 62.96 ± 6.96 to 57.81 ± 4.76, with a t-value of 5.505 ($p < 0.05$). Maximum Heart Rate (HRmax, bpm) dropped from 195.15 ± 8.50 to 178.40 ± 5.56, with a t-value of 10.76 ($p < 0.05$). These results highlight significant cardiovascular improvements of the training.

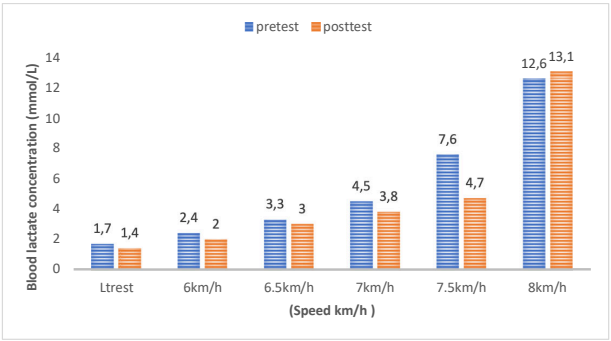

Fig. 1. Mean values of blood lactate concentration at various stages of incremental treadmill exercise and working load at every stage

This bar graph shows the blood lactate concentrations before and after the test at varying rates. The Anaerobic Threshold (AT), determined by the OBLA technique, is shown at 4 mmol/L. The blood lactate concentration is displayed in mmol/L on the y-axis, while the speeds are displayed on the x-axis in km/h. The lactate concentration level at which anaerobic threshold occurs is usually known as the OBLA (mmol/L).

Table 5. paired sample t test (control group)

Variables	RL (mmol/L)		OBLA (4 mmol/L)		Peak L 8km/h(mmol/L)	
Group	CON		CON		CON	
Test	pre	post	pre	post	pre	post
Mean	1.77	1.69	4.51	4.41	12.42	12.63
SD	.22	.22	.26	.21	1.12	.86
t value	2.693		1.86		-3.11	
Sig.2-tailed	.011		.072		.004	

Table 5 shows that the control group (CON) had mean resting blood lactate values of 1.77 ± 0.22 mmol/L before the test and 1.69 ± 0.22 mmol/L after the test. With a t-value of 2.693 ($p < 0.05$) and a minor difference between these averages, the intervention caused a significant decrease in resting blood lactate levels. The control group had mean OBLA values of 4.51 ± 0.26 mmol/L before the test and 4.41 ± 0.21 mmol/L after, with a t-value of 1.860 indicating no statistically significant change ($p > 0.05$) in OBLA levels, despite a slight decrease. The control group also had mean peak blood lactate values of 12.42 ± 1.12 mmol/L before the

Table 4. Paired sample t-test oflactate threshold speed, lactate threshold heart rate, resting heart rate, maximum heart rate of experimental group

Variables	LT speed(km/h)		LTHR(bpm)		HRrest(bpm)		HRmax(bpm)	
Group	EXP		EXP		EXP		EXP	
Test	pre	post	per	post	pre	post	pre	post
Mean	7.0	7.41	136.15	154.00	62.96	57.81	195.15	178.40
SD	0.0	.19	5.86	9.57	6.96	4.76	8.50	5.56
t value	11.59		15.05		5.505		10.76	
Sig.(2-tailed)	.000		.000		.000		.000	

Note: LT: Lactate Threshold; LTHR: Lactate Threshold Heart Rate; HR: Heart Rate

Table 6. Paired sample t-test oflactate threshold speed, lactate threshold heart rate, resting heart rate, maximum heart rate of control group

Variables	LT speed(km/h)		HR rest(bpm)		HR max(bpm)		LTHR(bpm)	
Group	CON		CON		CON		CON	
Test	pre	post	pre	post	pre	post	pre	post
Mean	6.92	6.95	69.62	64.09	192.40	185.78	131.12	135.81
SD	.18	.14	7.24	6.49	7.37	8.37	9.42	10.52
t value	1.0		5.53		6.11		-2.771	
Sig.2-tailed	.325		.000		.000		.009	

Note: LT: Lactate Threshold; LTHR: Lactate Threshold Heart Rate; HR: Heart Rate

test and 12.63 ± 0.86 mmol/L after. The t-value of -3.11 was statistically significant ($p < 0.05$), indicating a noteworthy change in peak lactate levels post-intervention, despite a modest increase in peak lactate.

Table 6 shows the control group (CON) had mean lactate threshold speed values of 6.92 ± 0.18 km/h before and 6.95 ± 0.14 km/h after the test. With a t-value of 1.0 ($p > 0.05$), the slight difference was not statistically significant, indicating no significant change in lactate threshold (LT) speed after the intervention. The group's mean resting heart rate (HRrest) increased from 64.09 ± 6.49 bpm to 69.62 ± 7.24 bpm, with a t-value of 5.53, significant at $p < 0.05$, suggesting improved cardiovascular fitness. Their maximum heart rate (HRmax) decreased from 192.40 ± 7.37 bpm to 185.78 ± 8.37 bpm, with a significant t-value of 6.11 ($p < 0.05$), reflecting a positive adaptation to the intervention. Lactate threshold heart rate (LTHR) increased from 131.12 ± 9.42 bpm to 135.81 ± 10.52 bpm, with a t-value of -2.771 ($p < 0.05$), indicating a statistically significant shift after the intervention.

This bar graph shows the blood lactate concentrations before and after the test at varying rates. The Anaerobic Threshold (AT), determined by the OBLA technique, is shown at 4 mmol/L. The blood lactate concentration is displayed in mmol/L on the y-axis, while the speeds are displayed on the x-axis in km/h. The lactate concentration level at which anaerobic threshold occurs is usually known as the OBLA (mmol/L).

Table 7 shows significant differences in all variables between the experimental (EXP) and control (CON) groups in the post-training analysis. The experimental group had a significantly higher OBLA (4.73 ± 0.15) compared to the control group (4.50 ± 0.26), with a substantial effect size

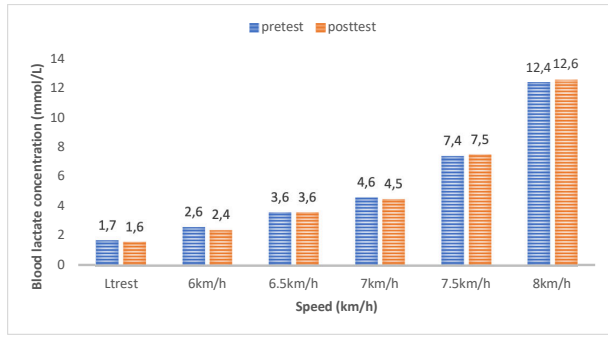

Fig. 2. Mean values of blood lactate concentration at various stages of incremental treadmill exercise and working load at every stage

(Cohen's d = 1.08, $p < 0.05$). Speed at lactate threshold (LT) was also significantly greater in the experimental group (7.40 ± 0.19) compared to the control group (6.95 ± 0.14), with a very large effect size (Cohen's d = 2.70, $p < 0.05$). For resting heart rate (HRrest), the experimental group showed a significant reduction (57.81 ± 4.76) compared to the control group (64.09 ± 6.49), indicating a training effect (Cohen's d = 1.10, $p < 0.05$). Maximum heart rate (HRmax) was significantly lower in the experimental group (178.40 ± 5.56) than in the control group (185.78 ± 8.37), with a notable training effect (Cohen's d = 1.04, $p < 0.05$). Lactate threshold heart rate (LTHR) was significantly higher in the experimental group (154.00 ± 9.57) compared to the control group (135.81 ± 10.52), with a large effect size (Cohen's d = 1.81, $p < 0.05$).

Table 7. Independent t test and Cohen's d test for measure of training effect post training

Variables	OBLA 4 mmol/L		LT speed (km/h)		HRrest(bpm)		HRmax(bpm)		LTHR(bpm)	
Group	EXP	CON	EXP	CON	EXP	CON	EXP	CON	EXP	CON
Test	post	post	post	post	post	post	post	post	post	post
Mean	4.73	4.50	7.40	6.95	57.81	64.09	178.40	185.78	154	135.81
SD	.15	.26	.19	.14	4.76	6.49	5.56	8.37	9.57	10.52
t value	4.162		10.35		-4.413		-4.147		7.229	
Sig .2-tailed	.000		.000		.000		.000		.000	
Cohen's d	1.08		2.70		1.10		1.04		1.81	
Effect Size	Large		Very large		Large (training effect)		Large (training effect)		Very large	

Discussion

In the experimental group, there was a significant decrease in RL from 1.72 ± 0.15 mmol/L to 1.42 ± 0.12 mmol/L ($p < .001$), with "t" value of 10.12 (Table 3). This decrease, with a Cohen's d of 1.08, indicates an improvement in aerobic ability which allows the body to process lactate more rapidly. This is in accord with the findings of Cao et al. (2021) and Favier et al. (1986) have ascribed it to increased oxygen use and mitochondrial efficiency. This lowering of RL is indicative to an improvement in the body's capacity to process lactate, this aspect which attributes a great deal for recovery and overall training response.

In the experimental group, OBLA slightly increased from 4.51 ± 0.26 mmol/L to 4.73 ± 0.15 mmol/L, with a t-value of 3.874 ($p < 0.05$). Although this increase was small, it reached statistical significance (Cohen's d = 1.08) and supported increased exercise intensities due to higher levels of lactate clearance in athletes. Ghosh (2004) highlighted that the athletes extending OBLA showed better performances even in endurance and intermittent sports, necessary for handball players. Studies by Losnegard et al. (2021), Ramadan & Mustafa (2023) confirm this conclusion as well, indicating that endurance training increase metabolic efficiency yield lactate production. According to Stanula et al. (2013) discussed byeven relatively modest improvements in lactate threshold permit higher work rates to be sustained over longer periods, a factor of critical importance for all aspects of handball matches.

There was also a small increase in the peak lactate levels reported at 12.66 ± 0.749 mmol/L and increased to 13.17 ± .74 mmol/L with t-value of 116.44. Despite improved lactate clearance, the increase in peak lactate during maximal exertion suggests enhanced anaerobic capacity, allowing athletes to produce more energy under high-intensity conditions. This is supported by Losnegard et al. (2021) and Cao et al. (2021), indicating that endurance training improves both aerobic and anaerobic systems. Sales et al. (2019) emphasized that anaerobic threshold improvements, like those seen in this study, are key to enhancing performance, especially during submaximal exercises.

Significant changes were observed in heart rate metrics, reflecting improved cardiovascular efficiency. Resting heart rate (HRrest) significantly decreased from 62.96 ± 6.96 bpm to 57.81 ± 4.76 bpm ($t = 5.505$, $p < 0.05$, Cohen's d = 1.10), while maximal heart rate (HRmax) dropped from 195.15 ± 8.50 bpm to 178.40 ± 5.56 bpm ($t = 10.76$, $p < 0.05$, $d = 1.04$). These reductions align with findings from Ghosh (2004) and Pennington (2015), indicating enhanced stroke volume and parasympathetic nervous system activity at rest. Additionally, the significant increase in lactate threshold heart rate (LTHR) ($t = 15.05$, $p < 0.05$, Cohen's $d = 1.81$) suggests that the athletes could sustain higher heart rates before reaching their lactate threshold, showing improved cardiovascular endurance. This is supported by Stefanov & Nejkov (2021), who reported that endurance training positively affects heart rate across different exercise intensities.

The control group (CON), which did not undergo specialized endurance training, showed limited physiological adaptations. RL levels decreased slightly from 1.77 ± 0.22 mmol/L to 1.69 ± 0.22 mmol/L, with a significant "t" value of 2.693 ($p < 0.05$), but changes in OBLA and LT speed were statistically non-significant. This suggests that regular handball practice, without structured endurance training, has a limited impact on improving lactate metabolism. The necessity for endurance training to achieve noticeable improvements in lactate metabolism was also emphasized by Svedahl & MacIntosh (2003) and Phillips et al. (1996).

The study demonstrates that endurance training significantly improved key metabolic and cardiovascular parameters in elite female handball players. Increases in OBLA, peak lactate, LTHR, and decreases in HRrest and HRmax point to enhanced aerobic and anaerobic capacity, allowing athletes to perform at higher intensities for longer periods. The large effect sizes (Cohen's d) across several variables emphasize the practical significance of these changes. These findings align with previous research, including that of Ramadan & Mustafa (2023), Losnegard et al. (2021), and Stanula et al. (2013), underscoring the importance of endurance training for competitive sports performance.

Conclusion

Eight weeks of endurance training program promotes large physiological changes in female handball players. Conclusions: An important finding of this study was a substantial reduction in resting blood lactate (RL), reflecting enhanced aerobic metabolism and lactate clearance. Greater peak blood lactate concentrations as well as an accompanying increase in OBLA and LT speeds indicate broader based tolerance for higher exercise workloads/ intensities, indicative of improved anaerobic potential. This increase in cardiovascular efficiency was confirmed by larger changes between baseline and post follow-up for LTHR, HRmax and HRrest. These results support the positive impact of structured endurance training to enhance aerobic and anaerobic performance among elite female athletes. The control group only saw a small improvement, which suggests periodized training is an essential aspect of performance enhancement in sports.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Вплив тренування з розвитку витривалості на показники концентрації лактату в крові та анаеробного порогу у бангладешських спортсменок-гандболісток

Шармін Актер Шанта[1ABCDE], Аджіта[1ABCDE]

[1]Пенджабський університет

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

Реферат. Стаття: 9 с., 7 табл., 2 рис., 28 джерел.

Історія питання. Тренування з розвитку витривалості відіграє важливу роль у покращенні аеробних здібностей та відтермінуванні настання періоду виснаження, що може позитивно позначитися на підвищенні результативності. Гандбол передбачає залучення як аеробних, так і анаеробних енергетичних систем людського організму. Тому розуміння впливу тренувань на такі фізіологічні показники, як анаеробний поріг і концентрація лактату в крові, набуває ключового значення.

Мета дослідження. Це дослідження мало на меті вивчити вплив програми тренувань з розвитку витривалості на показники анаеробного порогу та концентрації лактату в крові у бангладешських гандболісток.

Матеріали та методи. Загалом було відібрано шістдесят чотири спортсменки із застосуванням методики цілеспрямованої випадкової вибірки. Учасниць було розподілено за методом рандомізації на дві групи: експериментальна група – 32 особи та контрольна група — 32 особи. З метою оцінки рівня концентрації лактату в крові, анаеробного порогу, частоти серцевих скорочень у стані спокою та максимальної частоти серцевих скорочень використовували аналізатор лактату в крові, пульсоксиметр та тредміл-тест за протоколом Брюса (“Bruce protocol”).

Результати. В рамках дослідження спостерігалося значне поліпшення показників в експериментальній групі, зокрема зниження рівня концентрації лактату в крові у стані спокою з 1,72 ± 0,15 ммоль/л до 1,42 ± 0,12 ммоль/л на посттренувальному етапі. Крім того, відзначено збільшення періоду щодо початку процесу накопичення концентрації лактату в крові з 4,51 ± 0,26 ммоль/л до 4,73 ± 0,15 ммоль/л, а також зростання швидкості лактатного порогу з 7,0 ± 0,0 км/год до 7,49 ± 0,19 км/год. Також у контрольній групі було відмічено суттєве покращення таких показників, як частота серцевих скорочень у стані спокою, максимальна частота серцевих скорочень, концентрація лактату в крові у стані спокою та пікова концентрація лактату завдяки регулярним заняттям гандболом. Для визначення розміру ефекту щодо виконання тренувань на витривалість було розраховано показник d Коена (Cohen’s d). Результати застосування t-критерію для незалежних вибірок виявили істотні відмінності між експериментальною та контрольною групами ($p < 0,05$).

Висновки. Отримані під час дослідження дані свідчать про значний вплив тренувань з розвитку витривалості на показники анаеробного порогу та концентрації лактату в крові у бангладешських гандболісток.

Ключові слова: тренування з розвитку витривалості, концентрація лактату в крові, анаеробний поріг, початок процесу накопичення концентрації лактату в крові, гандболістки.

Information about the authors:

Shanta, Sharmin Akter: shantaakhter22@gmail.com; https://orcid.org/0009-0001-2997-6707; Department of Sports Science, Punjabi University, NH 64, next to Urban Estate Phase II, Patiala, Punjab 147002, India.

Ajita: ajita_dsingh@yahoo.co.in; https://orcid.org/0000-0003-4459-9249; Department of Sports Science, Punjabi University, NH 64, next to Urban Estate Phase II, Patiala, Punjab 147002, India.

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Original Scientific Article

Assessing Gender Dimorphism Indicators in Anthropometric Characteristics and Features of the Bony Pelvis of Female Representatives of Pair and Group Types in Sports Acrobatics

Nataliia Veronika Bachynska[1ABCDE], Eduard Doroshenko[2BCDE], Andriy Svatyev[3BCDE] and Victor Bohuslavskyi[1CDE]

[1]Dnipro State University of Internal Affairs
[2]Zaporizhzhia State Medical and Pharmaceutical University
[3]Zaporizhzhia National University

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

Corresponding Author: Nataliia Veronika Bachynska, e-mail: nat3vero@gmail.com
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Abstract

Objectives. The study aimed to examine individual anthropometric indicators, focusing on the bony pelvis size in female acrobats of various roles during the puberty and youth age, as well as in persons who do not engage in playing sports.

Materials and methods. The sports qualifications of female acrobats were sub-elite and elite athletes. The study population comprised 32 athletes having appropriate positions — top, middle, and bottom: (12 female acrobats performing their roles at the top, 20 female acrobats performing their roles in the middle and at the bottom). Girls of the same age categories (12-15 and 16-23 years old) who did not engage in playing sports (control group 1 and 2) also took part in the study. The research methods employed included the measurements of body length (cm), body weight (kg), shoulder width (cm), determination of body mass index (conventional unit); pelvimetry was performed to detect the transverse and longitudinal dimensions of the bony pelvis, as well as the degree of maturity of the pelvic bones using the index of pelvic bone (IPB). The methods of mathematical statistics were used to gain a comprehensive understanding of the data.

Results. A comparative analysis was conducted to identify the differences between female acrobats aged 12-15 years old and performing their roles at the top, female acrobats aged 16-23 years old and performing their roles in the middle and at the bottom, and control groups of the same age categories. The analysis revealed the presence of changes in morphofunctional indicators of the bony pelvis below the normative values during the study.

Conclusions. Morphological criteria of sexual dimorphism were found in female acrobats, namely: in the indicators of shoulder width and bony pelvis. These processes can be regarded as adaptive, occurring under the influence of physical and psychological training, as well as competitive loads of high intensity.

Keywords: sexual dimorphism, female acrobats, role, anthropometry, bony pelvis, pelvimetry.

Introduction

In modern research on sports medicine and morphology, the issues of studying the phenomena of masculinization, inversion of sexual dimorphism of female athletes are relevant. In the direction of further development of the general theory of sports and the system of training of athletes, the problematic issues of medical and biological research of the female organism in the process of training in Olympic and professional sports remain relevant (Shakhlina, 2020; Anderson et al., 2023; Nagorna et al., 2023; Nagorna et al., 2024).

Also relevant are studies aimed at studying and resolving the most controversial issues in the system of training women in various sports. In the study (Shueva, Ivashchenko, & Jagiello, 2021). It is shown that combined technologies of teaching complex coordination physical exercises using

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the algorithmic instructions method are effective for adapting the female body to training and competitive loads, which allow obtaining factor models of training programs at the level of 70.6% and 68.5% of the variation of results. The authors of the study (Andrieieva et al., 2020) note that combined fitness programs are effective for the female body, which allow to significantly increase the level of physical and functional fitness of the body. In turn, in sports activities this is the key to effective implementation of sports programs in complex coordination sports, especially in women's programs (Solohubova, et al., 2020).

Study authors (Douda et al., 2024), on materials of rhythmic gymnastics, by methods of factor analysis, the main components (with 45% variation of results) that affect the effectiveness of the training and competitive process were determined morphometric indicators account for about 6.8%. At the same time, the anthropometric component significantly affects the indicators of the overall effectiveness of sports training and competitive activity: $r = 0.5$ at $p < 0.01$. In the process of modeling, when applying the formulas of multiple regression equations to the indicators of qualified female athletes, it was determined that up to 33.6% (arm span – 12.0%, mid-thigh circumference – 13.1%, body weight – 8.5%) is accounted for by morphometric indicators that significantly differ by gender characteristics.

Also, gender specificities of somatotype and other morphometric characteristics were highlighted in the study (Sanchez Munoz et al., 2020), in which the indicators of running disciplines (middle and stayer distances) indicated the gender specificities of athletes who achieve maximum physical development in the age range of 17-23 years. This creates a basis for using the data obtained to optimize the control of the training process, as well as for more effective identification of talents and selection of athletes. Previously, similar results regarding the presence of gender specificities were obtained in the study – Altavilla et al. (2017).

The results of the study (Gonzalez Macias & Flores, 2024) indicate the existence of a relationship between somatotype indicators, body composition and flexibility manifestations. Differences were found between athletes of male rhythmic gymnastics (MAG), female rhythmic gymnastics (WAHS) and female rhythmic gymnastics (WAG) in terms of fat mass, bone mass, residual body mass, as well as the corresponding somatotype – endomorphic, mesomorphic and ectomorphic. These differences may indicate that somatotypes are associated with sports results, since the authors found correlations between anthropometric measurements, body composition and flexibility manifestations.

Opala-Berdzik, Głowacka, and Juras (2021) determined that the body mass index of acrobatic gymnasts and the BMI index are negatively correlated with the speed characteristics of the anterior-posterior and medial-lateral centers of foot pressure on the support in different visual conditions (r, from -0.64 to -0.93; at $p < 0.05$). The average speed indicators of the center of foot pressure in non-athletes are insignificantly correlated with their age and anthropometric indicators ($p>0.05$). The above indicates that female athletes – representatives of complex coordination sports, have peculiarities of physical development and specific morphometric manifestations, due to the adaptation of the body to training activities and the specifics of the sports orientation.

The results of long-term experimental studies (Atikovic, 2020) showed significant differences between female gymnasts in body weight and height over a 20-year period: from 1996 to 2016. No significant differences were found in the study materials of men in artistic gymnastics. The results presented are significant for determining comparative model parameters in the process of selection and sports specialization regarding morphological characteristics according to the gender characteristics of athletes – representatives of complex coordination sports. Of particular importance, in this case, are manifestations of age dynamics of the formation of vestibular stability and balance, which can also significantly differ in gender in representatives of complex coordination sports, as shown in experimental studies (Petran et al., 2023).

Special attention is paid to experimental studies aimed at studying the mental and physiological aspects of the human body. In particular, the problematic issues of body image and psychological resilience in view of the complex impact of social media and physical measurements on self-esteem and mental health of young athletes with an emphasis on their connection with cultural and gender factors are highlighted in the study (Merino et al., 2024). Also significant, from this point of view, are experimental studies aimed at gender differentiation of physiological indicators of optimal human mental state based on the identification of connections between neurotransmitters, hormones, inflammatory markers, microbiome and well-being (de Vries, van de Weijer, & Bartels, 2022). Active transformation of biologically active compounds to these substances occurs in the human body under the influence of optimal physical activity, which is relevant, namely, in the gender aspect (Curby et al., 2023). This is relevant both for young athletes and for women of early adulthood who are actively engaged in physical exercises and are involved in conditioning training to maintain the optimal physical status of their body (Shyshkina, & Beihul, 2023).

In experimental studies, based on materials from shooting sports (Bugaevsky, 2024), it was found that in the studied groups there are athletes of gynomorphic and mesomorphic sexual somatotypes, and there are no athletes of andromorphic sexual somatotype, which indicates either the peculiarities of the organism`s adaptation to specific training and competitive loads, or the effects of factors of the sports orientation of the specified contingent of athletes.

This scientific direction additionally raises the issue of the relationship between the somatotype and morphometric parameters of young female athletes with individual manifestations of neurological typology – the basis of these mechanisms are genetic factors and factors of adaptation to specific conditions of training activities in various sports (Tyshchenko et al., 2023).

Significant gender differences in the training process are also indicated by the authors of the study (Dave et al., 2022), who present the generalized results of a meta-analysis of gender differences in the frequency of repeated concussions in various sports with an emphasis on the group of complex coordination sports, which is significant for optimizing medical support for the process of sports improvement and reducing the level of sports injuries (Sheviakov et al., 2020).

The analysis of research works that thoroughly consider the issues of studying the features of adaptive changes in anthropometric and morphometric indicators of female rep-

resentatives of complex coordination sports, in particular, pair and group sports acrobatics, requires expansion and addition due to number of finally unresolved issues. Age, genetic, gender features of changes in physical development indicators, other anthropometric and morphometric indicators under the influence of factors of adaptation to the conditions of training activities and sports orientation are parallel processes in the conditions of development of the body of female athletes in the process of their many years of improvement. The above requires a detailed and in-depth study of these issues in the conditions of training in sports acrobatics, taking in to account the specific features of the female body, which allowed us to formulate the goal of our work.

Materials and Methods

Study Participants

Female athletes specialising in pair and group sports acrobatics of different roles and ages took part in the research: female athletes at the puberty age take their roles at the top (13.25 ± 1.65 years, n = 12), athletes of youth age take their part at the middle and at the bottom (19.34 ± 1.95 years old, n=20). The sports qualifications of female acrobats were sub-elite and elite athletes. The study population comprised 32 athletes having appropriate positions — top, middle, and bottom: (12 female acrobats performing their roles at the top, 20 female acrobats performing their roles in the middle and at the bottom). Girls of the same age categories (12-15 and 16-23 years old) who did not engage in playing sports (control groups 1 and 2) also took part in the study.

The studies were performed in accordance with all relevant national norms and rules of institutional policy and the National Health Council, according to the Declaration of Helsinki. All participants and parents of minors gave written agreement (consent) for the study and were informed of the purpose and procedures of the testing, as well as the possibility of withdrawing consent at any time for any reason. Informed consent was obtained from all individuals included in this study.

Study Organization

The study aimed to examine individual anthropometric indicators, focusing on the bony pelvis size in female acrobats of various roles during the puberty and youth age, as well as in persons who do not engage in playing sports.

Anthropometry was included in the research program: measurements of body length (cm), body weight (kg), shoulder width (cm), determination of body mass index (conventional unit).According to the classical method, pelviometry was performed with the detection of the transverse and longitudinal dimensions of the bone pelvis, as well as the degree of maturity of the pelvic bones using the index of pelvic bone (IPB) according to the modern methods (Wang, Asokan, & Onnela, 2024).

Statistical Analysis

Statistical processing was carried out using the STATISTICA 10.0 computer program and MS Excel XP software packages with an open license for non-commercial use. The main indicators of mathematical statistics were arithmetic mean (X), standard deviation (SD), standard error of the arithmetic mean (m), median, 25 % and 75 % quartiles. Comparison of indicators between samples of female acrobats of different roles with each other, as well as with the control group (population) was carried out using the non-parametric Mann-Whitney U-test (in cases where the sample didn't have a normal distribution) and Student's t-test (in cases when the sample had a normal distribution). In mathematical and statistical processing, the level of significance $\alpha = 0.05$ ($p < 0.05$) was used, in some cases the results were obtained at higher levels of significance ($p < 0.01$ and $p < 0.001$).

Results

The average height of female acrobats performing the function of those at the top role is 139.84 ± 3.89 cm, the average height of female athletes performing the roles in the middle and below is 163.47 ± 3.65 cm.

Differences between height and body weight indicators from female role partners those that are statistically significant in the middle and at the bottom (differences are reliable at $p < 0.001$) reflect the peculiarities of functional duties and specific activities during interaction in an acrobatic pair or group (Fig. 1).

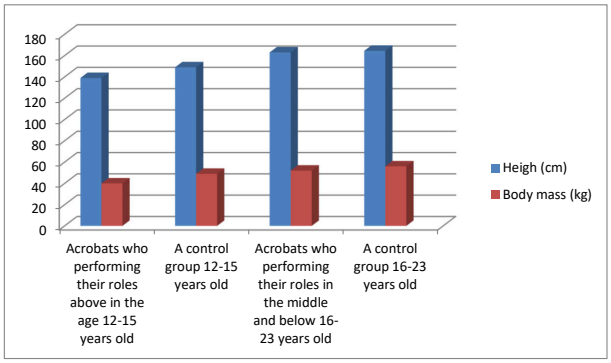

Fig. 1. Comparative characteristics of individual anthropometric indicators of female acrobats of different roles and the control group

Female acrobats of the roles above are statistically different from the population in terms of height and body weight ($p < 0.001$). According to the indicator of the body mass index (BMI), a deficit was found in female athletes of the above roles (Fig. 2).

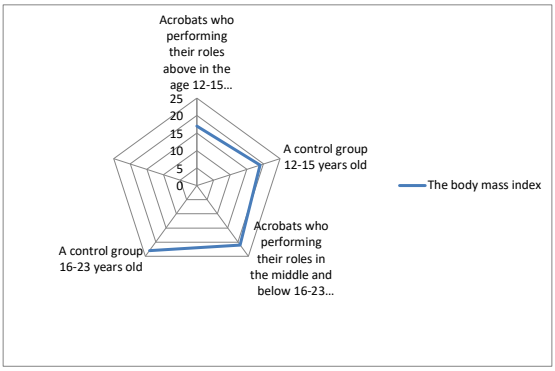

Fig. 2. Comparative characteristics of the body mass index (BMI) of female acrobats of different roles and the control group

Table 1. Indicators of pelvimetry and shoulder width, taking in to account the role of female acrobats and those who don't play sports, n = 64

No	Groups	Normative values (cm)	Statistical indicators			
			X ± SD	Me	25-75 %	P
			Shoulder width (biacromial size,)			
1.	exp. group 1 (n = 12)	–	30.51 ± 0.78	31.12	29.93-30.93	p1.2 < 0.05
2.	control group 1 (n = 12)		32.37 ± 0.80	32.76	31.49-32.89	p1.3 < 0.001
3.	exp. group 2 (n = 20)		36.00 ± 0.73	35.98	35.20-36.58	p2.4 < 0.05
4.	control group 1 (n = 20)		34.70 ± 0.51	34.65	34.17-34.98	p3.4 < 0.05
			Distantia spinarum (cm)			
1.	exp. group 1 (n = 12)	25-26	18.84 ± 0.43	20.25	19.89-20.67	p1.2 < 0.001
2.	control group 1 (n = 12)		23.63 ± 0.34	23.69	23.24-23.82	p1.3 < 0.001
3.	exp. group 2 (n = 20)		23.19 ± 0.56	23.17	22.73-23.17	p3.4 < 0.01
4.	control group 1 (n = 20)		25.69 ± 0.35	25.80	25.54-25.98	
			Distantia cristarum (cm)			
1.	exp. group 1 (n = 12)	28-29	23.95 ± 0.29	23.89	23.67-24.22	p1.2 < 0.01
2.	control group 1 (n = 12)		26.75 ± 0.29	26.75	26.51-26.97	p1.3 < 0.01
3.	exp. group 2 (n = 20)		26.12 ± 0.66	25.97	25.65-26.64	p2.4 < 0.01
4.	control group 1 (n = 20)		28.65 ± 0.33	28.64	28.37-28.98	p3.4 < 0.05
			Distantia trochanterica (cm)			
1.	exp. group 1 (n = 12)	30-32	25.29 ± 0.59	25.28	24.65-25.87	p1.2 < 0.01
2.	control group 1 (n = 12)		29.61 ± 0.34	29.51	29.32-29.77	p1.3 < 0.01
3.	exp. group 2 (n = 20)		28.11 ± 0.64	27.98	27.64-28.63	p2.4 < 0.05
4.	control group 1 (n = 20)		31.07 ± 0.65	30.84	30.49-31.76	p3.4 < 0.001
			Conjugata vera (cm)			
1.	exp. group 1 (n = 12)	11	9.84 ± 0.21	9.76	9.65-9.95	p1.2 < 0.05
2.	control group 1 (n = 12)		11.05 ± 0.22	11.03	10.87-11.23	p1.3 < 0.05
3.	exp. group 2 (n = 20)		10.57 ± 0.41	10.65	10.08-10.98	
4.	control group 1 (n = 20)		11.17 ± 0.15	11.18	11.12-11.25	
			Conjugata externa (cm)			
1.	exp. group 1 (n = 12)	20-21	16.92 ± 0.25	16.89	16.63-17.12	p1.2 < 0.05
2.	control group 1 (n = 12)		18.20 ± 0.27	18.22	17.89-18.34	p1.3 < 0.001
3.	exp. group 2 (n = 20)		19.05 ± 0.55	18.97	18.24-19.67	p2.4 < 0.05
4.	control group 1 (n = 20)		20.88 ± 0.29	20.98	20.72-21.04	p3.4 < 0.05

Notes: exp. group 1 – female acrobats at the roles above (12-15 years old); exp. group 2 – female acrobats at the roles in the middle and below (16-23 years old)

A comparative analysis of female acrobats performing roles at the top of 12-15 years old, female acrobats performing their roles at the middle and at the bottom of 16-23 years old, and control groups of the same age categories proves that the changes in the morphofunctional indicators of the bone pelvis below the normative values were detected during the research. This may be related to high and intense physical loads in the educational and training process of female athletes specializing in pair and group types of sports acrobatics, as well as the early period of sports. No pathological changes were detected in the control groups aged 12-15 and 16-23 (Table 1).

The indicators of shoulder width in female acrobats in the roles above, as well as in female athletes in the roles in the middle and below, exceed the indicators of pelvis width ($p < 0.05$).

Variability was revealed in individual anthropometric indicators in comparison with the control group. In girls aged 12-15 years old, the above indicators are statistically different from those in the control group ($p < 0.05$-0.001). In female acrobats of the roles in the bottom and in the middle, individual anthropometric indicators and the bone pelvis values have statistical differences compared to similar data in the group of roles at the top (90 % and 95 % confidence level).

The data obtained during the study regarding the size of the pelvis of female acrobats indicate an adaptive restructuring in their body and an inversion of sexual dimorphism. The analysis of the obtained data when measuring the width of the shoulders showed that these indicators exceed the dimensions of the width of the pelvis ($p < 0.05$). The average statistical values in the group are below the normative val-

ues, these indicators of female acrobats cannot be attributed to normative normal sizes, that is, they are female acrobats with indicators of an anatomically narrowed pelvis.

In the case of an individual assessment of the data obtained in two female acrobats, the roles in the middle and below, d. spinarum (cm) showed values close to the normative ones (24.67 and 24.54 cm), d. cristarum in two female acrobats (27.37 and 27.22 cm are close to the normative values). Also, one female acrobat has the role of the one in the middle, d. trochanterica (28.99 cm – approximate normative values).

The degree of maturity of the pelvic bones was determined according to the method using the index of the pelvic bone (IPB). It is an integral indicator of the formation of the bones of the pelvis. At the age of 12-13 years old, the highest peak increases in the size of the bone pelvis are observed. The same age is characterized by the appearance of menarche (Wang, Asokan, & Onnela, 2024).

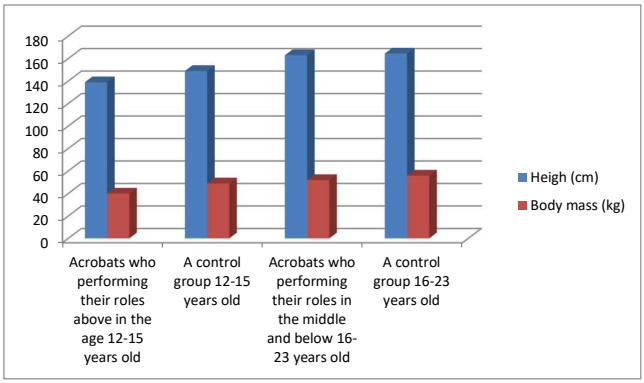

Fig. 3. Comparative characteristics of the index of pelvic bones (conventional unit) in acrobats of different roles and control groups (population)

In the average group values, this indicator was 28.25 ± 1.08 conventional unit in female acrobats performing their roles above (12-15 years old), that is, the process of formation of pelvic bone structures is observed in them. In the control group of the same age category, the value was 30.54 ± 1.11 conventional unit. ($p < 0.05$) (Fig. 3).

In female acrobats with roles in the middle and at the bottom of 16-23 years old, the IPB value is 32.45 ± 1.04 conventional unit, in the control group 36.34 ± 1.10 conventional unit (differences are significant at $p < 0.01$), i.e. the indicators are within the normal range, which indicates the completion of the process of maturation and formation of pelvic bone structures. For young female athletes, the normative values of IPB are indicators of 30-40 conventional unit. The age periods of the test subjects who took part in the experiment, namely puberty and youth ages, are critical periods of the process of formation and maturation of the pelvic bones.

Based on the data obtained during the study, female acrobats have shoulder width indicators that exceed those of the control group (population). The indicators of the width of the pelvis don't correspond to the norm (the difference is statistically significant at the probability level of 90 % and 95 %) (Table 1).

Discussion

The problematic issues of the influence of sexual dimorphism on anthropometric characteristics and features of the bony pelvis in female athletes – representatives of complex coordination sports – have received a detailed description in modern studies (Atikovic, 2020; Opala-Berdzik, Głowacka, & Juras, 2021; Petran et al., 2023).

In modern sport, the level of competitive results has reached such values that require female athletes to have the appropriate physical, morphological, functional, psychophysiological and mental abilities and data. Under the specific effect of training and competitive loads, certain structural changes are observed in the body of female athletes (Shakhlina, 2020).

Knowledge in the direction of studying the anthropometric and morphometric features of female athletes of puberty and youth, specializing in pair and group types of acrobatics, can help to rationally plan the training process at important stages of multi-year improvement. This can increase the quality of the construction of the educational and training process, the level of results of competitive activities and help to preserve reproductive health, slow down the process of rebuilding the body towards andromorphic development and help to control this process at a scientific level (Bachynska & Sarychev, 2023).

The increased level of androgens in the body of female athletes leads to the formation of a male somatotype, which is characterized by an increase in the width of the shoulders with a simultaneous decrease in the width of the pelvis. Experts also emphasize that the influence of androgens on the reproductive system of female athletes can be manifested in the suppression of the development of signs of puberty – growth of mammary glands, menarche, et al. (Hirschberg, 2020).

According to several authors, the early start of sport, namely before the onset of menarche, before the establishment of the menstrual cycle, as well as factors such as physical and psycho-emotional loads of high intensity, in a significant percentage of female athletes lead to a delay in puberty (especially in complex-coordinating types of sports). Mesomorphic and andromorphic sexual somatotypes are also formed. These processes are observed in the pubertal and adolescent age of female athletes (Andrieieva et al., 2020; Douda et al., 2024; Gonzalez Macias & Flores, 2024).

Specialists are investigating very important issues, namely the impact of training and competition loads on the reproductive functions of female athletes, the dependence of manifestations of masculinization of their bodies and high sports results. Scientists give examples that signs of sex inversion at the hormonal level affect the formation of a masculine body structure.

It is believed that female athletes with signs of masculinity are more successful in their chosen sport, therefore the search for morphological and other criteria that indicate signs of masculinization of female athletes is relevant at the current stage of research. During the sports selection of the requirements for the roles in the middle and below, the coaches emphasize such criteria of female athletes as broad shoulders, power qualities, special endurance, male psychological characteristics, that is, the manifestation of masculinization is a priority.

We consider the processes discovered during our research as adaptive changes in the body of female acrobats. They occur under the influence of physical and psycho-emotional loads of high intensity. We determined that all subjects had an early start to acrobatics (average age 7.25 ± 1.23), i.e. long before the onset of menarche. 98 % of subjects have already formed mesomorphic and andromorphic sexual somatotypes, which are explained in more detail in our previous publication (Bachynska et al., 2023).

Specialization and selection of female acrobats for the roles above and those in the middle and below should be carried out taking in to account not only the age difference of these female athletes, but also taking into account such anthropometric indicators as the length of the upper and lower limbs, the width of the shoulders and pelvis, morphofunctional index values. Adaptation to training and competitive loads of high intensity, reduction of fat mass, changes in neuro-humoral regulation of processes in the body of female athletes lead to changes in anthropometric, morphometric, and psychological characteristics of female acrobats (Shueva, Ivashchenko, & Jagiello, 2021).

Female pair group acrobatics is a specific type of specialization. The roles of those at the top and those in the middle and at the bottom (in pairs and groups) differ from each other primarily by anthropometric and morphometric indicators. In general, those partners above are younger in age, smaller in height and weight. They show signs of delayed puberty. Is this the result of loads or the specificity of selection, where the one at the top role should be light weight and smaller in height? Probably, both factors play a huge role here.

According to the requirements for the role of female athletes in pair and group pairs, there are anatomical, morphological and anthropometric features. The functional duties of those in the middle role (if a group) and those at the bottom role (pairs, groups) include are number of components: throwing, catching, supporting the partner at the top, on two and one hand, so these female athletes must be taller in height, weight and have significantly higher power indicators. That is, the training work includes exercises with the partner's body weight from 30 to 40-45 kg (depending on age categories and qualifications). This requires considerable strength and endurance, therefore, for female acrobats, the roles in the middle and those at the bottom, the training activity can be attributed to the so-called masculine. These factors can shape body image concerns in athletes across a variety of sports and skill levels. This is particularly important in acrobatics, where judges assess the level of difficulty of exercises with a certain level of artistry and aesthetic impact (Burgon, Beard, & Waller, 2023).

Prospects for further exploration in this direction lie in further differentiation of criteria for the success of competitive activity, which are associated with morphometric parameters and features of the formation of the bone pelvis in young female athletes. First, this concerns individual and pair-group types of sports acrobatics.

Conclusions

As a result of the research, it was found that the morphological criteria of sexual dimorphism were found in female acrobats who has their roles at the middle and below, namely: in the indicators of shoulder width and bone pelvis. These processes can be regarded as adaptive processes occurring in female athletes under the influence of physical, psychological training and competitive loads of high intensity.

When selecting for roles in acrobatic pairs and groups, coaches select female athletes based on height and body weight. It is also necessary to consider the anthropometric indicators of the width of the shoulders and pelvis, as well as other morphofunctional values. In the training process, it is necessary to differentiate training loads taking in to account the age characteristics of female athletes due to individual types of training process (individual elements, jumping on acrobatic tracks, general and special physical training exercises). This will make it possible to individualize the training process of female acrobats taking in to account their role and anthropometric and functional values, which will minimize the negative impact of loads on the body of young female athletes and preserve reproductive health. We cannot stop the growth of loads and change the specifics of the sport, but it is possible to slow down the process of morphofunctional adaptive changes (minimize this process) by controlling and planning the training process taking in to account the characteristics of the female body. It also requires individualization of load planning in such a way that the volume and intensity differ significantly from the training process of men.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Статевий диморфізм в антропометричних характеристиках та особливостях кісткового тазу представників парних і групових видів спортивної акробатики

Наталія Вероніка Бачинська[1ABCDE], Едуард Дорошенко[2ABCDE], Андрій Сватьєв[3BCDE], Віктор Богуславський[1CDE]

[1]Дніпровський державний університет внутрішніх справ
[2]Запорізький державний медико-фармацевтичний університет
[3]Запорізький національний університет

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

Реферат. Стаття: 8 с., 1 табл., 3 рис., 35 джерел.

Мета. Вивчення індивідуальних антропометричних показників, розмірів кісткової тканини тазу акробаток різного амплуа статевого та юнацького віку, а також осіб, які не займаються спортом.

Матеріали і методи. Контингент дослідження – 32 спортсменки (12 акробаток, амплуа – які зверху, 20 акробаток, амплуа – які посередині та внизу). У дослідженні також брали участь дівчата цих же вікових категорій (12-15 та 16-23 роки), які не займаються спортом (1 і 2 контрольна група). Методи дослідження: вимірювання довжини тіла (см), маси тіла (кг), ширини плечей (см), визначення індексу маси тіла (умовна одиниця); пельвіометрія з визначенням поперечного та поздовжнього розмірів кісток таза, а також ступеня зрілості кісток тазу за індексом тазової кістки (ІТК); методи математичної статистики.

Результати. Порівняльний аналіз показників акробаток (амплуа – верхні), 12-15 років, та акробаток (амплуа – середні та нижні), 16-23 років, дівчат і жінок контрольних груп тих самих вікових категорій доводить, що зміни у процесі дослідження виявлено за морфофункціональними показники кісткової тазової кістки, які зафіксовані на рівні нижче за нормативні значення.

Висновки. Виявлено морфологічні критерії статевого диморфізму у акробаток різного амплуа, а саме: за показниками ширини плечей, кісткового тазу. Ці процеси можна розглядати як адаптивні, що відбуваються під впливом фізичної та психологічної підготовки і змагальних навантажень високої інтенсивності.

Ключові слова: статевий диморфізм, акробатки, амплуа, антропометрія, кістковий таз, пельвіометрія.

Information about the authors:

Bachynska, Nataliia Veronika: nat3vero@gmail.com; https://orcid.org/0000-0002-0448-9187; Department of Special Physical Training, Dnipro State University of Internal Affairs, Nauky Ave., 26, Dnipro, 49005, Ukraine.

Doroshenko, Eduard: doroe@ukr.net; https://orcid.org/0000-0001-7624-531X; Department of Physical Rehabilitation, Sports Medicine, Physical Education and Health, Zaporizhzhia State Medical and Pharmaceutical University, Mayakovsky St, 26, Zaporizhzhia, 69035, Ukraine.

Svatiev, Andrii: 29011973@ukr.net; https://orcid.org/0000-0001-9399-1576; Department of Physical Culture and Sports, Zaporizhzhia National University, Zhukovsky St, 66, Zaporizhzhia, 69600, Ukraine.

Bohuslavskyi, Victor: nat3vero@gmail.com; https://orcid.org/0000-0003-2688-4505; Department of Special Physical Training, Dnipro State University of Internal Affairs, Nauky Ave., 26, Dnipro, 49005, Ukraine.

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Yogic Practices as a Complementary Approach to Physical Fitness: An Intervention Study

Tarak Nath Pramanik[1ABCDE], Aminur Rahaman[1ABCDE], Gopal Chandra Saha[2ABCDE], Anupam Roy[3ABCDE] and Punam Pradhan[1ABCDE]

[1]University of Delhi
[2]Visva-Bharati University
[3]University of Kalyani

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

Corresponding Author: Tarak Nath Pramanik, e-mail: dr.taraknath@gmail.com
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Abstract

Background. Yoga is an ancient practice that has gained attention for its potential benefits on muscular strength and endurance, flexibility, power, agility, balance, reaction time, and body mass index (BMI), making it an effective complementary approach for improving overall health and physical fitness.

Objectives. This study aimed to evaluate the effects of a six-week yogic regimen on overall health and physical fitness in male university students.

Materials and methods. Forty male students, aged 18 to 24, from the University of Delhi were randomly assigned to an experimental group or a control group, each comprising 20 participants. The experimental group underwent a six-week yogic intervention, including asanas, pranayama, and meditation, conducted daily under the guidance of certified instructors. The control group continued their usual daily routines. Pre- and post-intervention measurements were conducted to assess muscular strength, muscular endurance, flexibility, power, agility, balance, reaction time, and BMI. Data analysis involved both descriptive statistics and inferential statistics (paired and independent sample t-tests) using SPSS software (version 25), with a significance level set at $\alpha = 0.05$.

Results. The experimental group showed considerable improvements in muscular strength, muscular endurance, flexibility, power, agility, balance, reaction time, and BMI ($p < .005$). In contrast, the control group did not exhibit any notable changes in these parameters. Pre-test comparisons revealed no substantial differences between the experimental and control groups across any variables. However, post-test comparisons between the groups demonstrated significant differences in several key areas: muscular strength, muscular endurance, balance, and reaction time ($p < .005$). Conversely, no major differences were observed in flexibility, power, agility, or BMI ($p > .005$).

Conclusions. A six-week yogic intervention effectively enhances muscular strength, muscular endurance, flexibility, power, agility, balance, and reaction time, while reducing BMI in university students. Incorporating yoga into physical education and individualized training programs has the potential to significantly enhance fitness outcomes across diverse populations.

Keywords: yogic practice, muscular strength, muscular endurance, university student, physical fitness.

Introduction

Globally, young adults increasingly suffer from lifestyle disorders such as heart disease, stroke, metabolic syndrome, chronic obstructive pulmonary disease, obesity, diabetes, and several forms of cancer (Sahu et al., 2024). These conditions not only impair physical health but also cause significant social and economic challenges (Bhavanani, 2017). A primary contributor to this trend is the rise in sedentary activities among teenagers and young adults. Academic demands and extensive use of technology have significantly increased time spent sitting or engaging in low-

intensity activities, which has led to adverse health effects (Zhu, 2021). A sedentary childhood can harm heart health in adolescence and raise the risk of future cardiovascular diseases. To address these trends, schools and universities should implement inclusive physical education programs that promote fitness, skill development, and enjoyment for students of all fitness levels and interests (Neil-Sztramko et al., 2021).

One of the most significant health challenges facing college students today is the decline in physical activity levels. Research indicates that a substantial number of students do not meet the recommended activity guidelines, with approximately 46.7 % of university students engaging in insufficient physical activity (Kljajević et al., 2021). Core fitness is crucial for athletes, as it significantly influences their performance and well-being, directly affecting game-specific strategies and tactics (Reza et al., 2024). Healthy individuals can accomplish daily tasks energetically while reducing the risk of health problems (Berduszek et al., 2021). Regular physical activity is essential for athletes to maintain peak health, which is necessary for optimal performance. A well-rounded fitness and flexibility training program can enhance muscle strength, flexibility, and coordination, thereby reducing the risk of injury during training or competition and improving range of motion (Rahman & Islam, 2020).

Physical fitness enhances recovery after exercise, allowing well-conditioned to optimize training and extend their careers through efficient injury recovery (Malm et al., 2019; Singh et al., 2024). Muscular strength improve shoulder stability and upper-body strength, essential for activities like rock climbing and rowing, and assess relative upper-body strength since pulling muscles are generally weaker (Andrew, 2002; Harman et al., 2008; Negrete et al., 2013). Upper-body power boosts performance by enhancing force-time characteristics, demonstrated in cross-country skiing (Suchomel et al., 2016; Rahman & Sharma, 2023; Sunde et al., 2019). The sit-up test measures core muscular endurance, crucial for sustained performance and reduced fatigue (Bianco et al., 2015; Hughes et al., 2018; Prieto-González & Sedlacek, 2022). Flexibility supports joint range of motion and injury prevention, improved by consistent stretching (Leite et al., 2017). The Nordic hamstring curl is highly effective for improving hamstring flexibility and preventing injuries (Islam et al., 2024). Power training enhances daily functional abilities and quality of life (Balachandran et al., 2022; Miszko et al., 2003). Agility boosts neuromuscular coordination and cognitive health, benefiting both physical and mental fitness (Young et al., 2021; Morat et al., 2020; Lichtenstein et al., 2023). Balance enhances stability, coordination, and reduces fall risk, promoting independence. Reaction time, influenced by age and cognitive skills, is vital for quick responses in sports and daily tasks (Jain et al., 2015; Balakrishnan et al., 2014; Singh & Singh, 2024). BMI, an important health metric, impacts performance and training strategies, with lower BMI often aiding endurance athletes (Eknoyan, 2008; Nuttall, 2015; Blackburn & Jacobs, 2014).

Yoga, an ancient practice originating from India, encompasses physical postures known as asanas, breathing exercises called pranayama, and the skill of meditation (Taneja, 2014). Recognized for its efficacy in addressing lifestyle-related diseases, yoga plays a crucial role in improving overall physical well-being. The research underscores the benefits of regular yoga practice in preventing and managing lifestyle disorders, as highlighted by studies showing its effectiveness in promoting physical fitness and reducing stress, anxiety, and chronic discomfort (Bhavanani, 2017; Desveaux et al., 2015; Woodyard, 2011). Moreover, significant improvements in muscle strength, endurance, and body mass index (BMI) have been documented through yoga practice. For instance, Lau et al. (2015) and Shiraishi and Bezerra (2016) noted enhancements in muscular strength and endurance, while Kumara (2022) specifically reported a remarkable 12.5% increase in muscle strength among participants. Additionally, a recent study demonstrated that a structured six-week yogic practice resulted in a substantial 10.05% improvement in flexibility, further emphasizing yoga's ability to enhance flexibility over a short period (Suseela & Srilakshmidevi, 2017). In conjunction with these benefits, other research highlights notable improvements in power, agility, and balance among individuals who engage in regular yoga practice (Sahu, 2019; Henry, 2022). This is attributed to the mindful movement, breath control, and mental focus inherent in yoga, which positively influences reaction time and overall skill-related fitness. Specifically, studies indicate that yoga can enhance sensory-motor conduction velocity and information processing, leading to a reduction in reaction time (Madanmohan et al., 1992; Madanmohan et al., 2012). Furthermore, yoga has been shown to improve respiratory function, cardiovascular endurance, and overall health, reinforcing its holistic benefits (Pramanik et al., 2024). Importantly, consistent yoga practice has also been associated with reductions in BMI, effective weight management, decreased body fat, and increased muscle mass (Na Nongkhai et al., 2021; Chauhan et al., 2017). Collectively, these findings underscore the profound impact of yoga on various aspects of physical fitness and overall health.

This study aims to explore the effects of regular yogic practice on key fitness parameters – muscular strength, muscular endurance, flexibility, power, agility, balance, reaction time, and BMI – particularly in addressing lifestyle disorders prevalent in young adults due to sedentary behaviour. By examining existing research, the study seeks to demonstrate yoga's effectiveness as an alternative method to traditional fitness programs, offering significant benefits for overall health and well-being. The research highlights the potential of integrating yoga into physical education and training regimens as a core component of fitness protocols, with the potential to redefine training protocols across various disciplines.

Material and Methods

The published articles were located using several search engines, including MEDLINE, EMBASE, Scopus, Science Direct, the Directory of Open Access Journals (DOAJ), PubMed, and Google Scholar. Key search terms included "Yoga," "Muscular Strength," "Muscular Endurance," "flexibility," "power," "agility," "balance," "reaction time," and "BMI," along with the conjunctions "OR" and "AND." All searches were conducted in English, focusing specifically on studies that examine the impact of yogic practices on physical fitness variables for the literature review.

Participants

The study was conducted at the yoga laboratory of the Indira Gandhi Institute of Physical Education and Sports Sciences (IGIPESS), University of Delhi, involving 40 male students aged 18 to 24. These participants, all of whom had normal vision, were randomly assigned to either a control group or an experimental group, with 20 students in each group. In this study, none of the participants smoked, consumed alcohol, had acute or chronic diseases, or were on any medication. Table 1 provides an overview of the participants' characteristics. All participants were examined by a qualified physician and deemed fit to take part in this study. All participants gave their informed consent, confirming their voluntary participation and comprehension of the research procedures.

Table 1. Baseline characteristics of the participants

Parameters	Overall Group (N=40)	Experimental Group (n=20)	Control Group (n=20)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (years)	21.98 ± 0.94	21.53 ± 0.90	22.43 ± 1.01
Height (m)	1.69 ± 0.31	1.68 ± 0.30	1.70 ± 0.34
Weight (kg)	61.26 ± 5.95	59.69 ± 4.90	62.83 ± 5.20
BMI (kg/m^2)	21.45 ± 1.89	21.15± 1.29	21.74± 1.81

Study organization

This research adopted an experimental approach, using a two-group pre-test and post-test design. The aim was to determine if a six-week yogic intervention could significantly improve specific physical fitness parameters. Probability sampling methods were used to select participants from among the students.

Experimental Protocol

Participants in the experimental group followed a structured yoga regimen that featured Yogic Prayer, Suryanamaskar, and numerous Asanas, the program also incorporated Pranayama and included Meditation practices. These sessions took place at the IGIPESS yoga lab at the University of Delhi, from 7:30 to 8:30 am Monday to Saturday, under the supervision of certified yoga instructors. In contrast, the control group adhered to their usual daily routines without additional interventions. To measure the impact, assessments were made for all involved before the intervention began and after its completion at six weeks. Figure 2 provides an overview of this intervention.

Procedure

Muscular strength was assessed using the pull-up test, where participants pulled their chin above a bar from a hanging position with an overhand grip, avoiding jerking or hip movements, and the number of successful pull-ups was recorded as the score (Hurrah & Muzafer, 2017). Muscular endurance was measured using the bent knee sit-up test, with participants performing as many sit-ups as possible in one minute from a supine position, knees bent at 90 degrees,

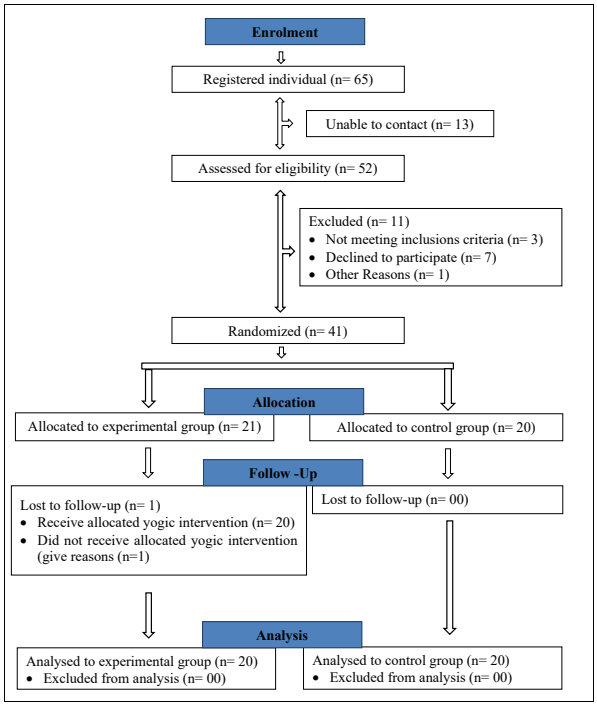

Fig. 1. Participations selection consort flow chart

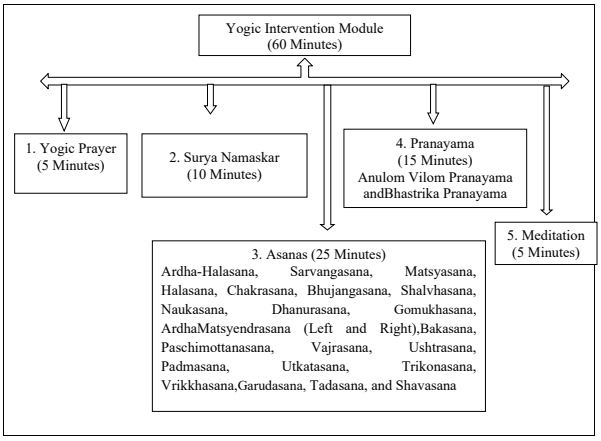

Fig. 2. Yogic intervention module

arms behind the neck, and feet held by a partner, earning one point per correct sit-up (Suman & Sharma, 2023). Flexibility was evaluated with the sit and reach test, where participants, seated with legs extended and feet against a plate, bent forward to push a cursor with their middle fingers, recording the highest of three attempts in centimeters (Luo & Huang, 2023). Power was assessed using the standing broad jump (SBJ), with participants jumping forward from a standing position and measuring the distance to the nearest heel (Thomas et al., 2020). Agility was tested with the shuttle run, running back and forth between two lines 10 meters apart at increasing speeds (Verschuren & Takken, 2010). Balance was measured through the squat handstand, where participants balanced on their hands with knees on their arms and held the position as long as possible for a single attempt. Reaction time was measured in milliseconds using the Medisystems

reaction timer, which had researcher-controlled lights and switches for subjects to turn off the lights quickly (Rahman & Islam, 2021; Reza et al., 2023). BMI was calculated by dividing body weight in kilograms by height in meters squared (Joksimović et al., 2021; Shaw et al., 2021).

Statistical Analysis

For the statistical analysis, the Shapiro-Wilk test verified the normality of data distribution, and Levene's test confirmed the equality of variances; descriptive statistics, including mean and SD, were used, while inferential analysis involved paired t-tests for within-group differences and independent samples t-tests for between-group comparisons, with all analyses conducted using IBM SPSS software (version 25) at a significance level of 0.05.

Results

Table 2 presents the descriptive statistics for the experimental (EG) and control (CG) groups, while Figure 2 illustrates changes in muscular strength, endurance, and BMI from pre-test to post-test, demonstrating the effectiveness in improving physical fitness.

Table 3 presents a paired t-test analysis results, demonstrating significant improvements in several physical fitness parameters within the experimental group (EG) following the intervention. The EG exhibited notable increases in muscular strength, $t_{(19)} = 5.18$, $p = .000$; muscular endurance, $t_{(19)} = 2.78$, $p = .012$; flexibility, $t_{(19)} = 5.15$, $p = .000$; power, $t_{(19)} = 2.51$, $p = .021$; agility, $t_{(19)} = 2.14$, $p = .046$; balance, $t_{(19)} = 2.85$, $p = .010$; and reaction time, $t_{(19)} = 2.35$, $p = .030$. Additionally, BMI significantly reduced

Table 2. Descriptive statistics

Variables	Group	Test	n	Mean	Std. Deviation	Std. Error Mean
Muscular Strength (Number)	EG	Pre-test	20	22.20	3.98	.89
		Post-test	20	23.85	3.56	.80
	CG	Pre-test	20	20.10	4.53	1.01
		Post-test	20	20.40	3.82	.85
Muscular Endurance (Number)	EG	Pre-test	20	36.10	4.48	1.00
		Post-test	20	37.00	4.80	1.07
	CG	Pre-test	20	33.45	6.44	1.44
		Post-test	20	32.65	6.67	1.49
Flexibility (centimetre)	EG	Pre-test	20	18.65	2.28	.51
		Post-test	20	19.60	1.96	.44
	CG	Pre-test	20	18.30	2.47	.55
		Post-test	20	18.50	2.31	.52
Power (meter)	EG	Pre-test	20	1.88	.28	.06
		Post-test	20	1.91	.25	.06
	CG	Pre-test	20	1.96	.10	.02
		Post-test	20	1.94	.10	.02
Agility (second)	EG	Pre-test	20	12.18	.97	.22
		Post-test	20	12.11	.95	.21
	CG	Pre-test	20	11.96	.48	.11
		Post-test	20	12.01	.50	.11
Balance (second)	EG	Pre-test	20	7.60	1.50	.34
		Post-test	20	8.20	1.47	.33
	CG	Pre-test	20	7.05	1.10	.25
		Post-test	20	7.00	.92	.21
Reaction Time (millisecond)	EG	Pre-test	20	15.75	1.02	.23
		Post-test	20	15.45	.95	.21
	CG	Pre-test	20	16.35	1.04	.23
		Post-test	20	16.20	1.06	.24
BMI (kg/m^2)	EG	Pre-test	20	21.15	2.64	.59
		Post-test	20	20.85	2.38	.53
	CG	Pre-test	20	21.92	2.26	.51
		Post-test	20	21.74	2.42	.54

Table 3. Paired t-test between the pre-test and post-test of the experimental and control groups

Variables	Group	Test	Mean Difference	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Muscular Strength	EG	Pre-test Post-test	1.65	1.42	.32	5.18	19	.000*
	CG	Pre-test Post-test	.30	2.72	.61	.49	19	.627
Muscular Endurance	EG	Pre-test Post-test	.90	1.45	.32	2.78	19	.012*
	CG	Pre-test Post-test	.80	1.88	.42	1.90	19	.072
Flexibility	EG	Pre-test Post-test	.95	.83	.19	5.15	19	.000*
	CG	Pre-test Post-test	.20	.62	.14	1.45	19	.163
Power	EG	Pre-test Post-test	.03	.06	.01	2.51	19	.021*
	CG	Pre-test Post-test	.01	.04	.01	1.46	19	.159
Agility	EG	Post-test Post-test	.07	.14	.03	2.14	19	.046*
	CG	Pre-test Post-test	.05	.19	.04	1.09	19	.288
Balance	EG	Pre-test Post-test	.60	.94	.21	2.85	19	.010*
	CG	Pre-test Post-test	.05	.83	.19	.27	19	.789
Reaction Time	EG	Pre-test Post-test	.30	.57	.13	2.35	19	.030*
	CG	Pre-test Post-test	.15	.59	.13	1.14	19	.267
BMI	EG	Pre-test Post-test	.30	.42	.09	3.18	19	.005*
	CG	Pre-test Post-test	.19	1.20	.27	.69	19	.498

*Significant at 0.05 level

for the EG, $t_{(19)} = 3.18$, $p = .005$. In contrast, the control group (CG) did not exhibit significant changes in these parameters: muscular strength, $t_{(19)} = .49$, $p = .627$; muscular endurance, $t_{(19)} = 1.90$, $p = .072$; flexibility, $t_{(19)} = 1.45$, $p = .163$; power, $t_{(19)} = 1.46$, $p = .159$; agility, $t_{(19)} = 1.09$, $p = .288$; balance, $t_{(19)} = .27$, $p = .789$; reaction time, $t_{(19)} = 1.14$, $p = .267$; and BMI, $t_{(19)} = .69$, $p = .498$ remained statistically insignificant.

These results strongly suggest that the intervention had a statistically significant impact on the experimental group's (EG) physical fitness outcomes. In contrast, the control groups (CG), which did not receive the intervention, showed no improvements across the same parameters. Consequently, this analysis underscores the efficacy of the intervention in enhancing physical fitness parameters specifically within the experimental group.

The independent t-test results presented in Table 4 show comparisons between the experimental group (EG) and control group (CG) for pre-test and post-test scores across multiple physical fitness variables, including muscular strength, muscular endurance, flexibility, power, agility, balance, reaction time, and BMI. In the pre-test, no significant differences were found between EG and CG in any of the variables. Muscular strength showed $t_{(38)} = 1.56$, $p = .128$; muscular endurance $t_{(38)} = 1.51$, $p = .139$; flexibility $t_{(38)} = .47$, $p = .644$; power $t_{(38)} = 1.19$, $p = .243$; agility $t_{(38)} = .91$, $p = .370$; balance $t_{(38)} = 1.32$, $p = .194$; reaction time $t_{(38)} = 1.84$, $p = .073$; and BMI $t_{(38)} = .99$, $p = .328$. However, in the post-test, several variables showed significant differences favoring the experimental group. Muscular

Table 4. Independent t-test of pre-test and post-test between experimental and control groups

Variables	Independent t-test between EG and CG of pre-test				Independent t-test between EG and CG of post-test			
	Mean Difference	t	df	Sig. (2-tailed)	Mean Difference	t	df	Sig. (2-tailed)
Muscular Strength	2.10	1.56	38	.128	3.45	2.96	38	.005*
Muscular Endurance	2.65	1.51	38	.139	4.35	2.37	38	.023*
Flexibility	.35	.47	38	.644	1.10	1.63	38	.112
Power	.08	1.19	38	.243	.04	.61	38	.549
Agility	.22	.91	38	.370	.11	.45	38	.652
Balance	.55	1.32	38	.194	1.20	3.09	38	.004*
Reaction Time	.60	1.84	38	.073	.75	2.37	38	.023*
BMI	.77	.99	38	.328	.89	1.17	38	.251

*Significant at 0.05 level

strength increased significantly in EG compared to CG with $t_{(38)} = 2.96$, $p = .005$, as did muscular endurance $t_{(38)} = 2.37$, $p = .023$, and balance $t_{(38)} = 3.09$, $p = .004$, and reaction time, $t_{(38)} = 2.37$, $p = .023$. No significant post-test differences were found for flexibility $t_{(38)} = 1.63$, $p = .112$, power $t_{(38)} = .61$, $p = .549$, agility $t_{(38)} = .45$, $p = .652$, and BMI $t(38) = 1.17$, $p = .251$.

These findings suggest that the experimental intervention led to significant improvements in muscular strength, endurance, balance, and reaction time in the experimental group, while other physical variables did not differ significantly between groups post-intervention.

Discussions

The results in Table 3 demonstrate significant improvements in muscular strength following the yoga intervention, particularly within the experimental group (EG) during both the pre-test and post-test stages. These findings align with a growing body of research that underscores yoga's effectiveness in enhancing muscular strength and overall physical fitness. For example, yogic practices can significantly enhance muscular strength, particularly in the upper body and core muscles, due to the intensity levels achieved through specific yoga postures (Lau et al., 2015). Moderate benefits of yoga practice on muscle strength, balance, mobility, and flexibility have also been observed (Shin, 2021). Additionally, yoga poses typically engage multiple muscle groups, contributing to overall strength gains (Sivaramakrishnan et al., 2019). Significant increases in muscular strength and endurance were noted following an 8-week yoga program for players, emphasizing yoga's utility in improving muscular capabilities across different populations (Singh et al., 2015). Furthermore, yoga's emphasis on alignment and posture plays a crucial role in optimizing muscular engagement and strength efficiency (Woodyard, 2011).

Building on these findings, the current study suggests that the yoga intervention led to significant improvements in muscular endurance for the EG compared to the CG. These findings align with earlier research on yoga's effects on muscular endurance. A 6-week yoga program notably enhanced upper limb and abdominal muscular endurance in young women (Shiraishi & Bezerra, 2016), and a 12-week yoga intervention improved abdominal endurance in young, healthy participants (Shiraishi et al., 2017). Consistent yoga practice over several weeks resulted in significant increases in both muscular endurance and flexibility, further supporting the link between yoga and physical fitness (Kame, 2018). Additionally, a 12-week yoga program significantly improved muscular endurance among working women in the textile industry, with gains linked to the regular practice of yoga asanas and Surya Namaskara (Kumar & Madaan, 2024).

Moreover, consistent research has demonstrated the positive effects of yoga interventions on flexibility among college students. Luo and Huang (2023) reported a significant improvement in flexibility, as measured by the sit and reach test, with p-values indicating statistical significance ($p < 0.05$). Similarly, Raja and Balaji (2024) found that participants in an experimental group engaging in yoga exhibited notable enhancements in flexibility compared to a control group. Further supporting these findings, Polsgrove et al. (2016) noted that students who participated in a structured yoga program showed significant improvements in flexibility over those who did not engage in yoga, suggesting that the dynamic and structured elements of yoga training are more effective for enhancing flexibility than traditional warm-up routines. Collectively, these studies highlight the efficacy of yoga as a beneficial practice for improving flexibility among college students.

Additionally, Studies have highlighted yoga's effectiveness in enhancing muscle power, with participants showing significant improvements after just six weeks of practice. For instance, Ghosh et al. (2023) observed substantial gains in muscle power, while Singh et al. (2021) found that even brief yogic interventions can produce measurable results. Similarly, Wankhade (2020) reported marked improvements in explosive power among college students, and Sandhyarani & Shenbagavalli (2014) noted significant gains in an experimental group practicing yoga, contrasting with a control group that showed no notable change.

In terms of agility, the current study indicated that participants who engaged in a yogic practice intervention experienced significant improvements in agility compared to a control group, with results showing statistical significance at the 0.05 level, highlighting that traditional training alone did not produce similar benefits (Singh, 2019). Similarly, another study found that practicing yogic techniques like asanas and pranayama led to significant agility improvements,

reinforcing yoga's potential to enhance physical fitness for both athletes and younger individuals (Sharma, 2019). Furthermore, an additional study revealed that a several-week yoga program could significantly enhance agility across various groups, including college students and general fitness enthusiasts.

In relation to balance, a study of a yoga intervention revealed that participants practicing yogasana showed significant improvements, suggesting that consistent yoga practice can lead to measurable enhancements in this area (Bhowmik & Ray, 2024). This finding is further supported by a systematic review and meta-analysis, which demonstrated significant improvements in balance from yoga interventions compared to inactive controls, while those engaged in alternative physical activities or no interventions did not experience similar benefits (Sivaramakrishnan et al., 2019).

Moreover, the results shown in Table 3 indicate a notable difference in visual reaction time (VRT) between the experimental and control groups. This observation aligns with prior studies, such as one by Madanmohan et al. (1992), which found that yoga practices significantly enhance reaction time. Furthermore, a meta-analysis by Ghuntla and Dholakiya (2023) supports this by confirming the beneficial effects of yoga on reaction time across various populations. Additionally, other research has indicated that short-term yoga training can effectively decrease baseline visual reaction times in healthy individuals (Begum et al., 2012). Interestingly, another study revealed that hand quickness in simple visual reaction tasks was comparable between university athletes and sedentary students (Rahman et al., 2020), suggesting that the benefits of yoga may extend beyond traditional athletic training. The observed reduction in VRT within the yoga group further suggests an improvement in sensorimotor skills and a greater processing capacity of the central nervous system among yoga practitioners, as indicated by Shobana et al. (2021). Physiologically, this improvement is evident in the time it takes for stimuli to reach the brain, which typically ranges between 20-40 ms for visual stimuli (Kemp, 1973; Marshall et al., 1943). Overall, these findings illustrate that yoga not only positively influences reaction time but also enhances sensorimotor skills and improves central nervous system processing capacity as a result of regular practice.

Finally, the findings from the current study align with the growing body of research supporting yoga as an effective intervention for reducing BMI and improving overall body composition. A systematic review and meta-analysis demonstrated that yoga is a safe and beneficial approach for addressing weight-related outcomes, particularly in individuals who are overweight or obese and highlighted yoga's potential as a complementary strategy to traditional weight management methods (Lauche et al., 2016). Consistent yoga practice over 8 to 12 weeks resulted in notable reductions in both BMI and body fat mass, which aligns with the current study's findings of significant improvements in body composition through regular yoga practice (Na Nongkhai et al., 2021). Decreases in BMI and other anthropometric measures were observed after a 1-month yoga program in obese individuals, reinforcing yoga's efficacy in managing obesity (Kumari et al., 2011). Yoga also significantly alleviated symptoms of anxiety and depression in overweight and obese individuals, alongside improvements in obesity, without dietary changes (Dhananjai et al., 2013). Consistent with these findings, the current study revealed a significant reduction in BMI (from 26.4 ± 2.5 to 25.22 ± 2.4) in the EC, with no changes seen in the CG, suggesting that yoga can effectively regulate BMI without requiring pharmacological intervention (Chauhan et al., 2017). Potential mechanisms, through which yoga might reduce BMI, such as increased energy expenditure during practice, add another dimension to understanding how yoga contributes to overall body composition improvements (Batrakoulis, 2022).

In summary, this study's findings align with existing literature demonstrating yoga's positive impact on muscle strength, muscle endurance, flexibility, power, agility, balance, reaction time, and BMI, further supporting its role as a holistic intervention for physical and mental well-being.

Conclusions

Based on the results, the experimental intervention is a robust method for improving key fitness parameters—muscular strength, muscular endurance, flexibility, power, agility, balance, reaction time, and BMI. The significant improvements observed in the experimental group, but not in the control group, confirm that these gains were due to the intervention itself. These findings highlight the intervention's potential utility in programs aimed at comprehensively enhancing physical fitness, offering both performance-related and health-related benefits. Future studies could investigate the long-term sustainability of these improvements and whether further enhancements could be achieved with extended or modified versions of the intervention.

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Conflict of Interest

The authors declare no conflicts of interest.

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Йогічні практики як допоміжний підхід до розвитку фізичної підготовленості: Інтервенційне дослідження

Тарак Натх Праманік[1ABCDE], Амінур Рахаман[1ABCDE], Гопал Чандра Саха[2ABCDE], Анупам Рой[3ABCDE], Пунам Прадхан[1ABCDE]

[1]Делійський університет
[2]Університет Вішва-Бхараті
[3]Університет Кальяні

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

Реферат. Стаття: 11 с., 4 табл., 2 рис., 82 джерела.

Історія питання. Йога є давньою практикою, яка привертає увагу своїми потенційними перевагами з точки зору впливу на розвиток м'язової сили та витривалості, гнучкості, сили, спритності, рівноваги, часу реакції та індексу маси тіла (ІМТ), що дає змогу використовувати цю методику як ефективний допоміжний підхід щодо покращення загального стану здоров'я та фізичної підготовленості.

Мета дослідження. Мета цього дослідження полягала в оцінці впливу шеститижневого режиму занять йогою на загальний стан здоров'я та фізичну підготовленість студентів університету чоловічої статі.

Матеріали та методи. У дослідженні взяли участь 40 студентів-чоловіків віком від 18 до 24 років з Делійського університету, яких було розподілено за методом рандомізації до експериментальної та контрольної груп, кожна з яких складалася з 20 учасників. Експериментальна група проходила шеститижневий курс занять йогою, що включав асани, пранаяму та медитацію, які проводилися щодня під керівництвом сертифікованих інструкторів. Контрольна група продовжувала виконувати свої звичні щоденні процедури. На перед- і постінтервенційному етапах дослідження проведено оцінку показників м'язової сили, м'язової витривалості, гнучкості, потужності, спритності, рівноваги, часу реакції та індексу маси тіла (ІМТ). З метою аналізу даних застосовували як описову статистику, так і інференційну статистику (t-критерії для парних і незалежних вибірок) із використанням програмного забезпечення SPSS (версія 25), з рівнем значущості $\alpha = 0,05$.

Результати. В експериментальній групі спостерігалося значне покращення показників м'язової сили, м'язової витривалості, гнучкості, сили, спритності, рівноваги, часу реакції та індексу маси тіла ($p < 0,005$). Натомість у контрольній групі не було виявлено жодних значущих змін у вищевказаних параметрах. Порівняльний аналіз на передтестовому етапі не показав суттєвих відмінностей між експериментальною та контрольною групами за жодною зі змінних. Однак проведення післятестового порівняльного аналізу між групами продемонстрували суттєві відмінності в кількох ключових аспектах: м'язова сила, м'язова витривалість, рівновага та час реакції ($p < 0,005$). З іншого боку, не спостерігалося достовірних відмінностей у показниках гнучкості, сили, спритності та індексу маси тіла ($p > 0,005$).

Висновки. Шеститижнева інтервенція із практики йоги сприяє ефективному підвищенню показників м'язової сили, м'язової витривалості, гнучкості, потужності, спритності, рівноваги та часу реакції, а також зменшенню індексу маси тіла у студентів університету. Включення йоги до програм фізичного виховання та індивідуальних тренувань має потенціал для значного поліпшення результатів фізичної підготовки серед різних груп населення.

Ключові слова: йогічна практика, м'язова сила, м'язова витривалість, студент університету, фізична підготовленість.

Information about the authors:

Pramanik, Tarak Nath: dr.taraknath@gmail.com; https://orcid.org/0009-0008-9322-6776; Indira Gandhi Institute of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Rahaman, Aminur: aminur.rahaman844@gmail.com; https://orcid.org/0000-0003-2248-845X; Department of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

Saha, Gopal Chandra: gopalchandra.saha@visva-bharati.ac.in; https://orcid.org/0000-0001-6813-4484; Department of Physical Education and Sport Science, Visva-Bharati University, Santiniketan, Bolpur, West Bengal 731235, India.

Roy, Anupam: cr7aroy@gmail.com; https://orcid.org/0009-0001-6480-6789; Prabharani Institute of Education, University of Kalyani, Kalyani, Nadia, West Bengal, 711202, India.

Pradhan, Punam: punampradhan746@gmail.com; https://orcid.org/0009-0003-7410-4419; Department of Physical Education and Sports Sciences, University of Delhi, Benito Juarez Marg, South Campus, South Moti Bagh, New Delhi, Delhi 110021, India.

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Linear Programming as a Tool for Managing the Training Process of Esports Teams

Oksana Shynkaruk[1ABCDE], Nataliia Byshevets[1ABCDE], Alla Aloshyna[2ABCDE], Olena Iakovenko[1ABCDE], Kostiantyn Serhiienko[1ABCDE], Valerii Pinchuk[1ABCDE], Oleksandr Petryk[1ABCDE] and Ivan Lut[1ABCDE]

[1]National University of Ukraine of Physical Education and Sports
[2]Lesya Ukrainka Volyn National University

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

Corresponding Author: Oksana Shynkaruk, e-mail: : shi-oksana@ukr.net
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Abstract

Background. Linear programming, with its ability to account for multiple constraints and optimize linear objective functions, is a promising tool for solving training planning tasks. This method enables the development of individualized plans tailored to the specific goals of each player and the team as a whole.

Objectives. This study aimed to develop linear programming variants for automating the planning process of esports teams' training schedules, enabling the allocation of workloads and determining the optimal distribution of time across various types of training while considering the individual characteristics of esports athletes, constraints, and diverse strategic goals.

Materials and methods. A comprehensive analysis of scientific, methodological, and specialized literature was conducted to ascertain the optimal use of resources, expert evaluation methods, linear programming, as well as statistical methods. Reliable statistical methods were employed: the dichotomous scale (results were processed using Cochran's Q concordance coefficient, which determined the consistency of expert opinions regarding each type of training); and the ratio scale (ranking) – the consistency of opinions was analyzed using Kendall's W concordance coefficient.

Results. An algorithm for determining the distribution of training workloads was proposed, which takes into account expert-defined ratios and constraints. To optimize the planning of the training process for esports teams, linear programming variants were developed, describing the distribution of time between different types of training as a linear programming task. Variant 1 serves for static time allocation between various training types without optimizing the distribution for specific goals. Variant 2 optimizes the time allocation, considering the individual characteristics of athletes and the strategic goals of the team. It incorporates constraints such as the total weekly training hours, the minimum required time for each type of training, and other limitations. The MS Excel Solver linear optimizer was used to find the optimal time distribution. Variant 2 facilitates the investigation of different scenarios for planning the training process of esports teams, demonstrating how the distribution of time across training types changes depending on set goals and preparation phases.

Conclusions. Based on the proposed algorithm, linear programming variants were developed, successfully addressing the task of automating the planning of esports team training. In contrast to Variant 1, Variant 2 offers an optimal distribution of time among different types of training (team training, individual training, physical activity sessions, etc.), considering the individual characteristics of players and the strategic goals of the team. It demonstrates high flexibility and adaptability to various esports disciplines, thereby allowing the investigation of different scenarios. The proposed approach can serve as a foundation for creating more advanced systems for managing the training process. Future research prospects include expanding the functionality of linear programming by incorporating additional factors such as psychological aspects, social dynamics within the team, and the physiological indicators of athletes.

Keywords: esports, management, training process, linear programming, workload, optimization.

Introduction

Esports, as one of the most dynamic sports disciplines, is characterized by rapid development and intense competition. However, despite significant progress, the training process for esports athletes still largely relies on the intuition of coaches and the individual experience of players, as noted by Chyzmar (2021) and Shynkaruk (2024). The lack of scientifically grounded methods that consider the individual characteristics of athletes and the fast-paced development of esports limits their potential and leads to inefficient use of time and resources. This inefficiency manifests in overtraining or undertraining, difficulty adapting to changes in the game, and decreased motivation.

The optimal distribution of training workloads is an important yet underexplored area of modern scientific research. One of the promising approaches is the use of linear programming. Linear programming enables the optimization of training programs, prediction of outcomes for various scenarios, and the creation of personalized training plans. The use of innovative tools based on linear programming will enhance the efficiency of planning the training process for esports athletes, ensure their sustainable development, and help achieve higher performance outcomes.

An analysis of recent studies and publications reveals that Bahrololloomi (2023), Nagorsky, and Wiemeyer (2020), and Novak et al. (2020) investigated phenomena and processes in sports, including esports, applying mathematical and statistical methods to confirm or refute hypotheses and identify new patterns. Several authors, including Shynkaruk et al. (2024), Byshevets et al. (2024), and Lazko et al. (2021), proposed predictive models and identified factors most influencing team victory.

Zhuk (2023) provides evidence of using mathematical modeling methods to develop simulation models aimed at improving the efficiency of detecting potentially suspicious match-fixing in football. According to Zhuk (2023), these methods can be adapted for identifying suspicious matches in other sports. Modeling issues have been addressed in works by Kostiukevych et al. (2023, 2024), Bezmylov (2024).

Chyzmar (2021) proposed a clear logic for formalizing the processes of esports development in Ukraine, revealing the basic mechanisms of the evolution of its subsystems (developers/publishers of games classified as esports disciplines, esports events, esports disciplines). This approach allows for assessing the impact of esports subsystems on the emergence of new communities and target formal groups and on diversifying esports disciplines.

Additionally, van Doornmalen (2023) and others highlighted the use of integer programming methods for tournament scheduling under a round-robin system, proposing solutions for cases of double round-robin systems where pairs meet twice in competitions.

A review of the scientific literature shows that existing mathematical models for optimizing the training process are often too complex for practical use in esports due to intricate mathematical apparatus and a focus on a narrow circle of specialists. This complexity arises from numerous formulas, abstract concepts, and the need for deep mathematical knowledge, as highlighted by Chyzmar (2023) and Shynkaruk et al. (2024).

On the other hand, Byshevets and co-authors (2020), as well as Hepler, Thangarajah, and Zizler (2016), demonstrate the successful application of linear programming methods using the MS Excel Solver optimizer in the training of specialists in physical culture and sports. Given the versatility and accessibility of this tool, we propose its use for solving similar tasks in esports. The MS Excel Solver allows for easy formulation of optimization problems in tabular form, parameter adjustments, and obtaining results in an understandable format. Furthermore, Techawiboonwong and Yenradee (2023) highlight that the linear programming algorithm employed by MS Excel Solver is well-studied and widely used in various fields, ensuring its reliability and efficiency. This approach enables coaches and athletes to independently create individual training plans without requiring specialized expertise, thereby simplifying the preparation process and increasing its effectiveness.

Despite significant progress in esports development, there remains a shortage of scientific research dedicated to creating individualized training plans that consider not only gaming skills but also the physical and psychological state of the athlete. While studies have been conducted on statistical data analysis and forecasting in esports, the potential of other mathematical methods, such as game theory, machine learning, and optimization, remains underexplored.

Linear programming, with its ability to account for multiple constraints and optimize linear objective functions, is a promising tool for solving training planning tasks. This method enables the development of individualized plans tailored to the specific goals of each player and the team as a whole.

The research hypothesis suggests that the application of linear programming using the MS Excel Solver optimizer will enable efficient planning of training workloads, potentially enhancing the performance of esports teams.

The purpose of the study was to develop linear programming variants for automating the planning process of esports teams' training schedules, enabling the allocation of workloads and determining the optimal distribution of time across various types of training while considering the individual characteristics of esports athletes, constraints, and diverse strategic goals.

Materials and Methods

Research Methods

The study involved a review and analysis of scientific, methodological, and specialized literature on the optimal use of resources, identifying the prospects for applying linear programming in the practice of esports.

Expert Evaluation

Expert evaluation played a key role in identifying the main types of training workloads in esports, their relative importance, and time constraints. This stage of the study involved professional esports athletes and specialists, providing a reliable foundation for further modeling and analysis.

Evaluation Parameters

The expert group consisted of 11 individuals: 7 professional esports athletes and 4 esports specialists. The experts

provided assessments regarding the importance and duration of various types of training required for the development of both beginner and professional players. The evaluations were conducted based on two main criteria:

1. Selecting the most important types of training from the proposed options.
2. Assessing the relative importance of each type of training in the preparation process.

Evaluation Methods

Reliable statistical methods were employed to analyze the data obtained from the experts:

Dichotomous Scale

Experts assessed training types using "Yes" or "No" responses. For example, they were asked to select the three most important types of preparation for beginners from seven options. The results were processed using Cochran's Q concordance coefficient, which determined the consistency of the experts' opinions on each type of training.

Ratio Scale (Ranking)

Experts ranked different aspects of training preparation by their level of importance. The consistency of their opinions was analyzed using Kendall's W concordance coefficient, enabling the identification of the most prioritized aspects.

Results of the Expert Evaluation

The experts identified the main types of training as the most crucial for the development of esports athletes, including:

- Technical training (improving game mechanics).
- Tactical training (strategies and team coordination).
- Psychological preparation (resilience to stress).

Time constraints and priorities were also established for each type of preparation, forming the basis for constructing mathematical models. The collected data provided the foundation for developing training task programs and optimizing the allocation of time across different types of workloads in esports.

Linear Programming

Linear programming was employed to design and optimize training plans for esports athletes. This method enabled a structured analysis of training processes, taking into account constraints and numerous variables to ensure precise and efficient workload distribution (Shynkaruk, Byshevets, Serhienko, Yakovenko, & Usychenko, 2024). Two variants of linear programming were developed to address different levels of complexity:

Linear Algebraic Equations (3×3)

The simpler variant (1) focused on the basic components of training. It provided insights into the primary relationships and dependencies between variables in the training process. By simplifying the system to a 3×3 matrix, variant 1 clearly visualized the key factors affecting training outcomes and offered a framework for optimizing these components with minimal computational complexity.

Linear Algebraic Equations and Inequalities (7×7)

The more complex variant (2) incorporated a broader range of variables and constraints. These equations described the intricate structure of the training system, accounting for complex interrelations and dependencies. Expanding the system to a 7×7 matrix enabled the simultaneous evaluation of multiple training scenarios, considering both fixed parameters and adjustable constraints. The inclusion of inequalities provided flexibility for exploring various training approaches and allowed variant 2 to account for specific limitations, such as maximum available time or resource constraints.

Linear Programming Approach

Both variants were formulated as linear programming tasks aimed at the optimal allocation of resources and workloads. Linear programming systematically supported decision-making by ensuring compliance with all constraints and maximizing or minimizing a defined objective function, such as overall training efficiency or time utilization.

Implementation with MS Excel Solver

The linear programming variants were solved using the MS Excel Solver optimizer. This tool delivered efficient computations and visualization of optimal solutions within the set constraints. The Solver's functionality allowed researchers to explore various scenarios by adjusting parameters and constraints, dynamically enhancing training plans for esports athletes. The solutions provided practical recommendations on resource and time allocation across different training components to achieve strategic goals.

Statistical Analysis

To ensure the reliability of data obtained during the study, several methods of mathematical statistics were employed. These methods focused on assessing the consistency of expert opinions and the significance of the findings.

1. Cochran's Q Concordance Coefficient

Cochran's Q criterion was applied to evaluate data assessed on a dichotomous scale (e.g., "Yes" or "No"). The primary purpose was to determine the degree of agreement among expert assessments in tasks requiring the selection of the most important types of preparation from a predefined set. The Q formula accounts for the variability in expert choices and evaluates whether their assessments are random or consistent. The significance of the results was tested by comparing the computed Q value with the critical χ^2 value at a significance level of $\alpha = 0.05$.

2. Kendall's W Concordance Coefficient

Kendall's W coefficient was used to measure the consistency of expert opinions when ranking the importance of various preparation aspects. Unlike dichotomous assessments, Kendall W considers the order of importance assigned by each expert. The W value is calculated based

on the deviation of individual rankings from the average ranking, which reflects the level of agreement among experts. A high W value indicates strong agreement. The significance of the results was also tested using the χ^2 criterion at $\alpha = 0.05$.

3. Statistical Verification

All concordance coefficients were subjected to significance testing to confirm their reliability. The χ^2 criterion was used to test the hypothesis of randomness or agreement in the results. Calculations were automatically performed using the Statistica software package. The statistical significance of the concordance results was tested using the χ^2 criterion at a significance level of $\alpha = 0.05$. This ensured the accuracy and reliability of the collected data. All calculations were performed using the Statistica software package (StatSoft, USA).

Results

Given the specifics of esports, planning training sessions with different focuses is a particularly complex task. Based on the results of a comprehensive review of scientific and methodological literature on optimizing various types of planning tasks under limited material and time resources, as well as personal experience, we believe that planning diversified training for esports athletes requires special attention.

We begin with a simplified problem of time allocation among various types of training for esports players at the initial stage of preparation. To mathematically describe the real system that represents the planning of esports athletes' training processes, experts identified the most effective training types necessary for successful mastery of an esports discipline by novice players. They also established the types of mathematical relationships (equations, inequalities) and interdependencies among these elements.

Below is an example illustrating the consistency of expert opinions regarding the most effective types of training for novice esports athletes and their weekly durations. In the first case, experts were asked to select the most effective training types for beginners in esports, and in the second case, to specify the number of hours needed for each type of training (Table 1).

Similarly, relationships between the types of training were identified, confirming the consistency of expert opinions ($p < 0.05$).

Then, the problem statement for **Variant 1** is as follows: In the esports training program for novice athletes, there are three types of training focuses: tactical, technical (game mechanics), and psychological. The coach plans to allocate a total of 15 hours to these three types of training as follows: the time allocated to tactical training should be twice that of technical training, and the time allocated to game mechanics training should exceed that of psychological training by 3 hours. How many hours should be allocated to each type of training?

Solution. To solve the problem, we formulated a linear programming variant as a system of linear algebraic equations. Let *x, y, z* represent the hours allocated to tactical, technical, and psychological training, respectively. Then, the SLAE describing the stated requirements is as follows:

$$\begin{cases} x + y + z = 15 \\ x = 2y \\ y = z - 3 \end{cases} \quad (1)$$

We can write the problem in the form of a system of linear algebraic equations (SLAE), ensuring that all unknown variables are on the left side of the equals sign and all constant terms are on the right side:

$$\begin{cases} x + y + z = 15 \\ x - 2y = 0 \\ y - z = -3 \end{cases} \quad (2)$$

Here:

x represents the hours allocated to tactical training.

y represents the hours allocated to technical training (game mechanics).

z represents the hours allocated to psychological training.

The system of linear equations can be written in matrix form as $AX = B$, where:

$$A = \begin{pmatrix} 1 & 1 & 1 \\ 1 & -2 & 0 \\ 0 & 1 & -1 \end{pmatrix}; \quad X = \begin{pmatrix} x \\ y \\ z \end{pmatrix}; \; B = \begin{pmatrix} 15 \\ 0 \\ -3 \end{pmatrix} \quad (3)$$

Here:

A is the coefficient matrix.

Table 1. Determination of Linear Programming Variant Parameters

Training Focus	Expert Agreement (Focus Type) Q = 13.309; df = 6, p < 0.0384		Weekly Duration (Hours)	Expert Agreement (Duration) Q = 16.363; df = 6, p < 0.0119	
	No, %	Yes, %		No, %	Yes, %
Theoretical Training	54.5	45.5	5	81.8	18.2
Physical Training	45.5	54.5	10	90.9	9.1
Tactical Training	9.1	90.9	15	45.5	54.5
Game Mechanics (Technical Training)	-	100.0	20	90.9	9.1
Teamwork and Communication	45.5	54.5	25	100.0	-
Psychological Training	36.4	63.6	30	90.9	9.1
Self-Game Analysis	54.5	45.5	35	100.0	-

Note: Q – Cochran's concordance coefficient; df – degrees of freedom calculated as (n−1)(n-1)(n−1), where n is the number of evaluated objects; "No," "Yes" – percentage of experts who chose a specific response to a question

X is the column vector of unknowns (x, z).

B is the column vector of constants.

It should be noted that the elements of matrix A reflect the relationships between different types of training, while the elements of matrix B represent the constraints on the training load times. The main matrix of the system combined with the matrix of constants forms the augmented matrix of the system:

$$A\tilde{} = \left(\begin{array}{ccc|c} 1 & 1 & 1 & 15 \\ 1 & -2 & 0 & 0 \\ 0 & 1 & -1 & -3 \end{array}\right) \quad (4)$$

Let us solve the problem using the MS Excel Solver linear optimizer.

The key parameters for finding solutions are:

Constants – the augmented matrix of the SLAE.

Changing cells – the matrix X, which contains the unknown variables , representing the distribution of hours allocated to different types of training (for convenience, the matrix X is represented as a row rather than a column).

Objective function (OF) – the resulting indicator for which the linear optimizer selects the best values (it should be noted that in the absence of a predefined function to be optimized, any cell containing a formula can be used as the objective function).

Constraints – these are the conditions that must be considered during the optimization of the objective function.

Let us consider the algorithm for applying linear programming and the MS Excel Solver optimizer, adapted to our task, which will have the following structure (Fig. 1).

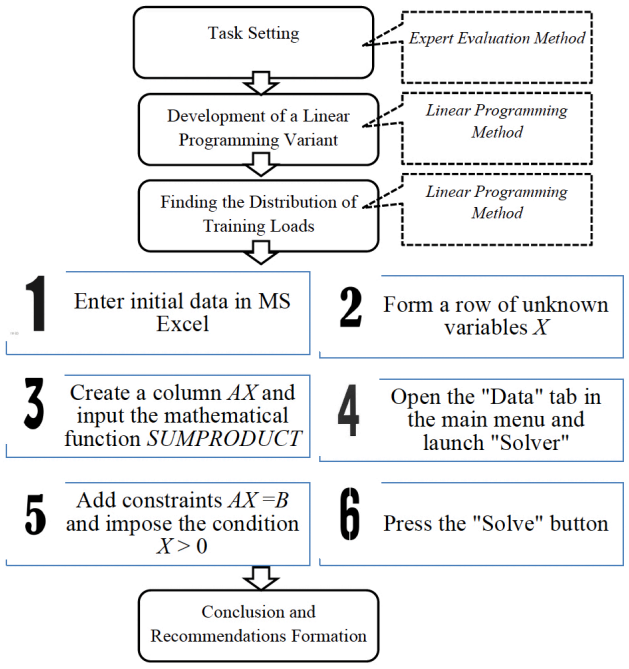

Fig. 1. Algorithm for Determining the Distribution of Training Loads Considering Expert-Defined Ratios and Constraints

The result of the training load distribution using MS Excel tools is presented in the figure (Fig. 2).

Thus, novice esports players at the initial stage of preparation should allocate 6 hours to tactical training, 3 hours to technical training (game mechanics), and 6 hours to psychological training. Using this approach, we were able to optimally distribute training time among various types of loads, considering all imposed constraints.

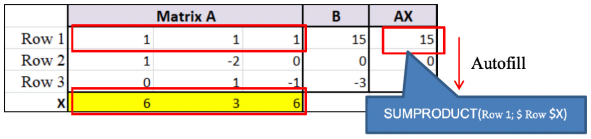

Fig. 2. Result of Training Load Distribution

Let us consider a more complex scenario where various factors need to be taken into account and multiple indicators need to be optimized simultaneously.

We adapt the proposed algorithm for determining the distribution of training loads, taking into account the ratios and constraints identified by experts. It is important to emphasize that the parameters of the linear programming variant were also determined based on expert experience and the consistency of their opinions on each aspect of the training process considered in the variant. It should be noted that as the complexity of the planning task increases, changes will occur at step 5 of the training load distribution process. This step will be supplemented by step 6 – the introduction of an objective function, ensuring the optimal distribution of time for different types of training and allowing for the exploration of various scenarios.

Variant 2. A team of 5 esports athletes needs to distribute time and resources among various types of preparation to optimize their performance before an important tournament. Several key areas are involved in preparation: team training, individual training, match analysis, use of technical resources, working with the coach, psychological support, and recovery (physical activity sessions).

Solution. Let us define the following variables: x_1– time for team training (hours); x_2 – time for individual training (hours); x_3 – time for match analysis (hours); x_4 – use of technical resources (units); x_5 – time for working with the coach (hours); x_6 – time for psychological preparation (hours); x_7 – time for recovery through physical activity (hours).

The problem includes the following conditions and constraints:

Total time and resources are limited to 50 hours per week. Individual training should take 1.2 times more time than team training. Time for match analysis should be 5 hours more than time spent working with the coach. Psychological support should take 3 hours less than recovery. Technical resources should be proportional to the time spent on match analysis, with a coefficient of 0.8. Time spent on working with the coach and team training together should be at least 15 hours. Recovery time should not exceed 10 % of the total time.

Thus, the mathematical model of the problem is a system of 7 linear algebraic equations and inequalities.

As in the previous case, we will input the initial data and configure the necessary settings to obtain the solution using the Solver add-in. Specifically, we will:

Form the column AX: Use the SUMPRODUCT function to calculate the sum of the products of the rows of matrix A and the row of unknowns X.

$$\begin{cases} x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 = 50 \\ x_2 = 1{,}2 \cdot x_1 \\ x_3 = x_5 + 5 \\ x_6 = x_7 - 3 \\ x_4 = 0{,}8 \cdot x_3 \\ x_1 + x_5 \geq 15 \\ x_7 \leq 0.1 \cdot 50 = 5 \end{cases} \Rightarrow \begin{cases} x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 = 50 \\ -1{,}2x_1 + x_2 = 0 \\ x_3 - x_5 = 5 \\ x_6 - x_7 = -3 \\ -0{,}8x_3 + x_4 = 0 \\ x_1 + x_5 \geq 15 \\ x_7 \leq 5 \end{cases}$$

Apply the calculation to the entire column: Extend the formula to include all rows.

Step 5 adjustments (Figure 1) add the constraints to the Solver configuration:

$J$2:$J$5=$I$2:$I$5 (The first four components of the system are equations);

$J$6:$J$7>=$I$6:$I$7; $J$8<=$I$8 (The last three components are inequalities);

$B$9:$H$9>=1 (The esports athlete must complete all types of training);

$B$9: $H$9>= whole (The training time must be an integer).

These steps ensure the proper setup of the problem within MS Excel Solver to find an optimized solution based on the defined mathematical model and constraints. Click the "Find Solution" button to obtain the result (Fig. 3).

	A	B	C	D	E	F	G	H	I	J
1		Matrix A							B	AX
2	Row 1	1	1	1	1	1	1	1	50	50
3	Row 2	-1,2	1						0	0
4	Row 3			1		-1			2	2
5	Row 4									
6	Row 5			-0,8	1				0	6
7	Row 6	1				1			15	16
8	Row 7							1	5	4
10	X	15	18	3	8	1	1	4		

SUMPRODUCT(B2:H2;$B$9:$H$9)

Fig. 3. Result of weekly training load planning for esports athletes

Thus, each player in the esports team should plan for 15 hours of team training, 18 hours of individual preparation, 3 hours for match analysis, 8 hours of training with technical resources, 1 hour for working with the coach, 1 hour for psychological preparation, and 4 hours for physical activity per week.

The proposed variant is based on linear programming methods and allows for the exploration of different training process scenarios, adjusting the balance between team and individual training, analyzing gameplay situations, physical activity sessions, and more. However, in real-world tasks, it is often the case that multiple competing objectives exist, requiring a compromise solution.

Therefore, in the process of planning training load durations, we can introduce an objective function that enables formalizing the set tasks and finding the optimal allocation of resources. Even if the basic variant has a single solution, introducing an objective function allows us to make it more flexible and adaptable to various scenarios. For example, we may aim to allocate more attention while balancing the duration of activities such as team and individual training and physical activity sessions. In this case, the objective function would take the following form:

$$Z = x_1 + x_2 + x_7 \rightarrow \max \quad (5)$$

It can be observed that the introduction of the objective function (OF) significantly altered the distribution of time among different types of training. Specifically, the time allocated for physical activity increased to 5 hours. With the time distribution shown in the row in the figure (Figure 4), the objective function will reach its maximum value of 38 hours allocated to the specified types of training. At the same time, the total weekly training duration remains unchanged at 50 hours.

	A	B	C	D	E	F	G	H	I	J
1		Matrix A							B	AX
2	Row 1	1	1	1	1	1	1	1	50	50
3	Row 2	-1,2	1						0	0
4	Row 3			1		-1			2	2
5	Row 4						1	-1	-3	-3
6	Row 5			-0,8	1				0	1
7	Row 6	1				1			15	17
8	Row 7							1	5	5
9	Z	1	1					1	OF	38
10	X	15	18	4	4	2	2	5		

Fig. 4. Result of optimizing weekly training load for esports athletes

Similarly, the coefficients in the objective function can be adjusted to observe how this affects the distribution of time allocated for training. This approach allows us to understand how sensitive the result is to changes in the input data (Fig. 5).

It should be noted that the constraints ensure the minimum inclusion of all types of loads, while the objective

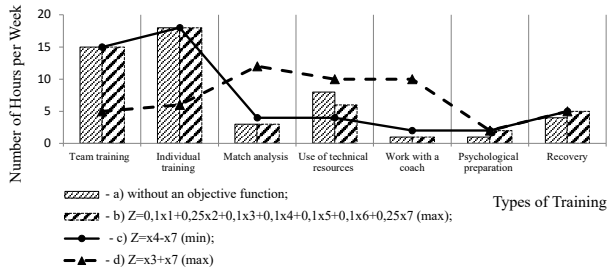

Fig. 5. Optimization of time allocation in the training process of esports athletes: comparison of different scenarios

function determines which types of loads are prioritized. The figure sequentially presents the following graphs:

Without an objective function – for distributing the training load volume under predefined conditions.

With an objective function, that maximizes the overall effect of the training process, prioritizing individual training and physical activity.

With an objective function aimed at minimizing the imbalance between time spent at the computer and physical activity to ensure balanced athlete development.

With an objective function, that shifts focus toward maximizing and balancing time spent on match analysis and physical activity while distributing other types of loads considering predefined constraints.

The proposed Variant 2 for allocating time to different types of training can be applied both to an esports team, taking into account the coach's objectives, and to individual players to address weaknesses and develop strengths.

Thus, the developed Variant 2 of linear programming, aimed at supporting decision-making in the planning of esports teams' training, is flexible and accommodates priority objectives, training phases, and the individual characteristics of each athlete.

Variant 2 enables the exploration of various training process scenarios and determines the optimal allocation of time among training types, considering the individual characteristics of players, constraints, and diverse strategic goals.

Discussion

The study revealed that potential applications of mathematical methods in esports include optimizing team composition, where the problem can be formulated as a system of linear equations with unknowns. The coefficients in these equations represent the effectiveness of each player for a specific role. Moreover, this approach opens avenues for an in-depth analysis of game data, where systems of linear algebraic equations (SLAE) can be effectively employed to determine relationships between various game parameters (e.g., the number of opponents defeated, deaths, assists) and match outcomes. It has also been demonstrated that linear programming can be successfully applied to strategy development by representing different game scenarios as SLAEs, with the unknowns being the optimal actions of the players.

The findings from this study highlight the versatility of linear programming for solving planning tasks in esports training processes. The proposed approach to workload distribution allows for easy adjustments of task conditions and facilitates the exploration of various scenarios depending on set objectives, making it a practical tool for esports.

An algorithm for distributing training workloads was proposed, taking into account expert-defined proportions and constraints. This algorithm is flexible and can be adapted to address a variety of planning tasks in esports training.

Two linear programming variants were developed to model the training process of esports players, describing the allocation of time across different types of training while considering established constraints, such as the total number of training hours per week. Using the simplex method of linear programming, implemented via the MS Excel Solver add-in, an optimal allocation of time that best aligned with set objectives was determined in each case.

Further programming, involving adjustments to the weighting criteria for training duration in the objective function of Variant 2, enabled an examination of how priority changes affect the optimal time distribution among different types of training.

The results align with the findings of Matos et al. (2022), Techawiboonwong, Yenradee (2023), and Yang et al. (2024). For instance, Techawiboonwong and Yenradee (2023) outlined an algorithm for developing an optimal aggregate production plan that includes data collection, problem formulation, solution determination using the MS Excel Solver add-in, solution evaluation, and implementation in production. This approach demonstrated effectiveness in project planning, particularly in scheduling tasks to achieve minimum total project costs. Our findings extend and validate the work of Valenko and Klanšek (2017), who proposed addressing project time optimization problems using the MS Excel Solver add-in, with subsequent data transfer to MS Project for further management and presentation of optimized time planning solutions.

Authors such as Alexander, Le, Tsiango (2018), and Minami et al. (2024) share the view, which we fully support, that implementing linear programming in well-known software environments enhances its practical applicability.

Summarizing the data from scientific and methodological literature and our own positive experience in applying linear programming in physical education and sports (Byshevets et al., 2020; Shynkaruk, Lut, Pinchuk, Vasyliyev, 2024), we proposed employing a similar approach to address practical challenges in esports. Our previous research demonstrated the effectiveness of using linear programming with the MS Excel Solver in decision-making for esports management (Shynkaruk et al., 2024), enabling continued exploration in this area.

Conclusions

Linear programming enables the consideration of multiple constraints, such as time, resources, and players' physical capabilities, which are inherent to the challenges of planning training regimens for esports athletes. The use of the MS Excel Solver add-in automates the search for an optimal training time allocation plan, allowing esports coaches and players to make scientifically informed decisions regarding training schedules, thereby enhancing their overall efficiency.

Based on the proposed algorithm, linear programming variants have been developed that successfully address the automation of training plan optimization for esports teams. Unlike Variant 1, Variant 2 provides an optimal distribution of time across different types of training (team training, individual training, physical activity sessions, etc.), taking into account the individual characteristics of athletes and the strategic goals of the team. It demonstrates high flexibility and adaptability to various esports disciplines and allows for the exploration of different scenarios. The proposed approach can serve as a foundation for the creation of more complex systems for managing the training process.

This study clearly illustrates how linear programming methods can be utilized to substantiate training plans, paving the way for new opportunities to improve the preparation of esports athletes.

Conflict of Interests

The authors state that there is no conflict of interests.

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Лінійне програмування як засіб управління тренувальним процесом команд в кіберспорті

Оксана Шинкарук[1ABCDE], Наталія Бишевець[1ABCDE], Алла Альошина[2ABCDE], Олена Яковенко[1ABCDE], Костянтин Сергієнко[1ABCDE], Валерій Пінчук[1ABCDE], Олександр Петрик[1ABCDE], Іван Лут[1ABCDE]

[1]Національний університет фізичного виховання і спорту України
[2]Волинський національний університет імені Лесі Українки

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

Реферат. Стаття: 10 с., 1 табл., 5 рис., 23 джерела.

Історія питання. Лінійне програмування, завдяки своїй здатності враховувати множинні обмеження та оптимізувати лінійні цільові функції, є перспективним інструментом для вирішення задач планування тренувань. Цей метод дозволяє розробляти індивідуальні плани, які відповідають конкретним цілям кожного гравця та команди в цілому.

Мета. Розробити варіанти лінійного програмування для автоматизації процесу планування тренувального процесу кіберспортивних команд, які дозволять розподіляти навантаження та знаходити оптимальний розподіл часу між різними видами тренувань з урахуванням індивідуальних особливостей кіберспортсменів, обмежень та різних стратегічних цілей.

Матеріали і методи. Аналіз науково-методичної та спеціальної літератури з питань оптимального використання ресурсів, методи експертних оцінок, лінійного програмування, статистичні методи. Застосовувалися надійні статистичні методи: дихотомічна шкала (результати оброблялися за допомогою коефіцієнта конкордації Кохрана (Q), який визначав узгодженість думок експертів щодо кожного виду тренувань); шкала відносин (ранжування) - узгодженість думок аналізували за допомогою коефіцієнта конкордації Кендалла (W).

Результати. Запропоновано алгоритм знаходження розподілу тренувальних навантажень, який передбачає урахування визначених експертами співвідношень і обмежень. Для оптимізації планування тренувального процесу кіберспортивної команди розроблено варіанти лінійного програмування, які описують розподіл часу між різними видами тренувань як задачу лінійного програмування. Варіант 1 слугує для статичного розподілу часу між різними видами тренувань, не оптимізуючи цей розподіл під конкретні цілі. Варіант 2 оптимізує розподіл часу, враховуючи індивідуальні характеристики спортсменів та стратегічні цілі команди. Він враховує такі обмеження як загальна кількість годин тренувань на тиждень, необхідний мінімальний час на кожен вид тренування та інші обмеження. Для пошуку оптимального розподілу часу було використано лінійний оптимізатор MS Excel Розв'язувач. Варіант 2 дозволяє досліджувати різні сценарії планування тренувального процесу кіберспортивної команди, демонструючи, як змінюється розподіл часу на види тренувань залежно від поставлених цілей та фази підготовки.

Висновки. На основі запропонованого алгоритму розроблено варіанти лінійного програмування, які успішно вирішують завдання автоматизації планування тренувань кіберспортивних команд. На відміну від варіанту 1, варіант 2 пропонує оптимальний розподіл часу між різними видами тренувань (командні тренування, індивідуальні тренування, заняття руховою активністю тощо) з урахуванням індивідуальних особливостей спортсменів та стратегічних цілей команди. Він демонструє високу гнучкість та адаптивність до різних дисциплін кіберспорту і дозволяє досліджувати різні сценарії. Запропонований підхід може бути використаний як основа для створення більш складних систем управління тренувальним процесом. Перспективами подальших досліджень є розширення функціоналу лінійного програмування шляхом включення додаткових факторів, таких як психологічні аспекти, соціальна динаміка в команді та фізіологічні показники спортсменів.

Ключові слова: кіберспорт, управління, тренувальний процес, лінійне програмування, навантаження, оптимізація.

Information about the authors:

Shynkaruk, Oksana: shi-oksana@ukr.net , https://orcid.org/0000-0002-1164-9054 , Department of eSports and Information Technologies, National University of Ukraine on Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

Byshevets, Nataliia: bishevets@ukr.net; https://orcid.org/0000-0001-6118-6580; Department of eSports and Information Technologies, National University of Ukraine on Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

Aloshyna, Alla: aleshina1012@gmail.com; https://orcid.org/0000-0001-6517-1984; Head of the Department of Sports Theory and Physical Education, Lesya Ukrainka Volyn National University, Lutsk, Ukraine.

Iakovenko, Olena: elena1988.ia@gmail.com; https://orcid.org/0000-0002-7165-5229, Department of Esports and Information Technologies, National University of Ukraine on Physical Education and Sport, Fizkultury St, 1, Kyiv, 03150, Ukraine.

Serhiienko, Kostiantyn: miytrener@gmail.com; https://orcid.org/0000-0001-9199-6007; Department of Esports and Information Technologies, National University of Ukraine on Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

Pinchuk, Valerii: vpinchuk@uni-sport.edu.ua; https://orcid.org/0009-0000-1902-3606; Lecturer of the Department of Esports and Information Technologies, National University of Ukraine of Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

Petryk, Oleksandr: opetryk@uni-sport.edu.ua; https://orcid.org/0000-0003-3387-8410; Lecturer of the Department of Esports and Information Technologies, National University of Ukraine of Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

Lut, Ivan: ivan.lut2014@gmail.com; https://orcid.org/0009-0003-6428-9990; Lecturer of the Department of Esports and Information Technologies, National University of Ukraine of Physical Education and Sport, Fizkultury St, 1, Kyiv, 03680, Ukraine.

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Promoting Inclusion and Well-Being Through Inclusive Physical Education and Parasports: an Approach for Adolescents with Motor Impairment

Omar Ben Rakaa[1ABCD], Mustapha Bassiri[1ABCD] and Said Lotfi[1ABCD]

[1]Hassan II University of Casablanca

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

Corresponding Author: Omar Ben Rakaa, e-mail: : omarbenrakaa@gmail.com
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Abstract

Objectives. This study aimed to examine the impact of inclusion students with motor impairment (MI) into adapted physical education (APE) and school para-athletics on their feeling of pedagogical and school inclusion, as well as on their psychological well-being and self-esteem.

Materials and methods. The study involved 96 pupils having motor impairment, aged 16.79 ± 0.87, enrolled in public schools in Morocco. The pupils were divided into three groups according to the para-athletics classification: 30 % (family of 30), 40 % (families of 40) and 30 % (family of 50). The participants were randomly assigned into three groups: a control group with no specific programme, a group following an APE programme (24 sessions), and a third group with APE and additional para-athletics sessions (24 sessions), including competitions for three months. The assessments were carried out before and after the intervention. The scales were employed to gauge self-esteem, psychological well-being, as well as feeling of pedagogical and schooling inclusion.

Results. The findings indicate that students who engaged in both the APE and para-athletics programmes exhibited enhancements in their feeling of pedagogical and schooling inclusion, psychological well-being, and self-esteem, when compared to the control group. The group that participated in both APE and para-athletics demonstrated the most significant progress in this study.

Conclusions. The findings suggest that the integration of adapted physical education and inclusive sports, including para-athletics, into school curricula in a systematic manner represents a pivotal element in promoting inclusion, well-being and self-esteem among students with motor impairments.

Keywords: motor disability, psychosocial development, educational equity, school inclusion strategies, adapted sports, adapted physical activity.

Introduction

The existing literature on the inclusion of students with special educational needs (SEN) in education systems worldwide has become a significant area of concern, supported by a multitude of international frameworks (Direction des Curricula, 2019b, 2019c, 2019a; UNESCO, 2005). The most significant of these is the United Nations Convention on the Rights of Persons with Disabilities (2008), which places particular emphasis on the necessity of inclusive education for all children (United Nations, 2008). This shift towards inclusive education is indicative of a growing awareness of the importance of equity and equal opportunity in educational environments (Lindsay Smith et al., 2017). Concurrently, the advantages of physical activity on mental and physical health are well substantiated in the literature (El Moutaraji et al., 2021a, 2021b; WHO, 2020). Such outcomes include a reduction in stress levels, an improvement in quality of life, and a general sense of well-being (Biddle & Asare, 2011). Nevertheless, the inclusion of students with motor impairment (SWMI) into physical education programmes continues to present a significant challenge (Mokmin & Rassy, 2024). A review of the literature reveals that SWMD encounter a range of physical, social, and pedagogical obstacles that restrict their participation in traditional sports activities (Ballas et al., 2022; Chomistek et al., 2019; Sammon et al., 2020). To illustrate, a study demonstrated that physical barriers, including access to infrastructure, and negative social atti-

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tudes impede the capacity of disabled students to participate in physical activities to their fullest extent (Block & Obrusnikova, 2007). Furthermore, the absence of comprehensive training for educators on the inclusion of SWMD in sports programmes was identified as a significant barrier to their participation (Vickerman & Maher, 2019).

It is imperative that physical activities are adapted and that inclusive school sports programmes are implemented in order to overcome the aforementioned challenges. Indeed, research demonstrates that these approaches can not only enhance the inclusion of students with motor impairment, but also facilitate their physical and psychosocial development (Risyanto et al., 2024). It is thus imperative that educational organisations modify their curricula to align with the specific requirements of these students, thus facilitating a more inclusive and equitable educational experience (Stentiford & Koutsouris, 2022). The particular research context serves to highlight the significance of adapted physical education (EPA) as a constituent element of inclusive education (Martín-Rodríguez et al., 2024; Torres-Castro et al., 2021). Students with motor impairment encounter particular challenges that may impede their engagement in physical activities (Ben Rakaa et al., 2024b), such as physical limitations and low self-esteem (Alhumaid et al., 2021). A recent study has demonstrated that the incorporation of adapted physical activity can not only enhance physical capabilities but also foster improvements in self-esteem and general well-being (Wickman et al., 2018). The integration of inclusive school sports facilitates the social and educational inclusion of pupils with impairment (Hovdal et al., 2021). The creation of an environment in which all students, irrespective of their physical abilities, are able to participate in sporting activities serves to foster the development of an inclusive culture that extends beyond the confines of the classroom (Lieberman et al., 2024).

The evidence indicates that inclusive school sports programmes have a beneficial impact on the motor and social skills of students with special educational needs (SEN) (Nalbant Correspondence & Sibel Nalbant, 2018). Furthermore, these programmes have the potential to mitigate feelings of isolation and cultivate more constructive interpersonal relationships among students, thereby facilitating their integration into the school community (Wickman et al., 2018). It is of the utmost importance to continue researching and developing strategies for the inclusion of adapted physical education (EPA) and inclusive school sports, such as para-athletics, to facilitate the inclusion of students with motor impairment in mainstream educational settings. These approaches have the potential to improve not only the physical and mental health of students with motor disorders, but also their school and pedagogical inclusion, as well as their well-being and self-esteem. In light of the growing emphasis on this topic, it is essential to examine how school practices can facilitate such inclusion. In particular, this study examines the influence of the inclusion of children with motor-impaired in APE and school para-athletics on their feeling of school and pedagogical inclusion, as well as on their psychological well-being and self-esteem.

Materials and Methods

Study Participants

The study was conducted on a sample of 96 participants with motor impairment, aged 16.79 ± 0.87, enrolled in regular public schools in different regional academies in Morocco. The participants were distributed as follows: 35 % lived in rural areas and 65% lived in urban areas. The participants were selected according to the following inclusion criteria: they were enrolled in a regular class with able-bodied pupils, they held a disability certificate issued by Entraide Nationale, and they had a medical certificate of physical fitness allowing them to participate in physical education classes. Parents or legal guardians provided informed consent for their children's participation in the study and for the publication of the results. Prior to their inclusion, the participants were subjected to the International Paralympic Committee's disability classification system (International Paralympic Committee, 2016), which was conducted by volunteer experts in the field. The classification system revealed that 40% of the participants were eligible to take part in throwing disciplines (field), while 60 % were able to take part in running and/or jumping disciplines (track). Of these, 30 % had cerebral impairment, 40% had amputations or similar, and 30% had motor impairment due to spinal cord injuries.

Protocol

This study used the randomized controlled trial (RCT) method to evaluate the impact of two adapted physical activity (APA) programs : the adapted physical education (APE) program alone and the combined APE+Para-athletics program. Participants were randomly divided into three distinct groups to minimize selection bias.

The first control group did not participate in any specific program during the study period. The second group (EPA) followed an EPA program, consisting of two weekly sessions of one hour each, focused solely on EPA for a period of three months.The third group (EPA+Para-athletics) benefited from the same EPA program as the second group, with the addition of two extra sessions per week of 1h30 each, dedicated to performance Para-athletics. This group also took part in inclusive school sport competitions at provincial, regional and national levels in school Para-athletics.

The school-based adapted physical activity (APA) programme has been designed with the specific needs of students with motor impairment in mind. The programme focuses on two main athletic disciplines: throwing and running/jumping. It is designed for educational purposes in the teaching and learning cycles (APE) as well as for sporting purposes within the framework of inclusive school sport. In doing so, it takes into account the classifications of motor impairment (cerebral deficiencies, amputations, spinal cord injuries) in order to encourage the practice and physical participation of students in PE classes, with the ultimate goal of gradually including them in competitive sports.

The students' physical education and sports (PE) teachers devised learning cycles in the form of an APE programme, tailored to the profile of their students with motor impairment, as part of their PE teaching cycles. Subsequently, Para-athletics training programmes were established with the objective of optimising sporting performance, and students were integrated into provincial, regional and national competitions as part of an inclusive school sport initiative.

The programme is structured in three phases: initiation, development and consolidation. The intensity of

the programme is progressive, with the level of difficulty adapted to the individual abilities of the students. Regular assessments and individualised progress monitoring facilitate the adaptation of session content according to the performance of each participant, while encouraging participation in inclusive sports competitions to foster the students' physical and social development. In both programmes, a pre-test and post-test were conducted, with the Psychological Well-Being, Self-Esteem and sense of pedagogical and school inclusion. Scale administered on each occasion.

Measuring Instrument

Self-esteem

The Rosenberg Self-Esteem Scale (RSES) is a widely used instrument for the assessment of global self-esteem. The scale comprises ten statements, which are rated on a four-point Likert scale, with the subject indicating the extent to which they agree or disagree with each statement. It is a reliable and straightforward measure that is employed in a multitude of psychological, educational and clinical contexts (Vallieres & Vallerand, 1990).

Psychological Well-being

The Ryff Psychological Well-Being Scale is a comprehensive assessment tool that evaluates six fundamental dimensions of well-being, namely autonomy, environmental mastery, personal growth, positive relationships, purpose in life and self-acceptance. The scale was developed in 1989 and employs a Likert scale to quantify the aforementioned aspects. This instrument is frequently employed for the assessment of psychological well-being in a multitude of cultural and clinical contexts (Ryff, 1989).

Pedagogical Inclusion Scale

The current scales, namely the Sense of Pedagogical Inclusion (SPI) scale and the Sense of school Inclusion Scale (SSI), are founded upon the Norwegian iteration of Booth's Inclusion Index (Booth & Ainscow, 2002). Subsequently, the data was incorporated into a face-to-face survey of a representative sample of students with special educational needs at various grade levels. The responses were then subjected to an in-depth thematic analysis, which enabled the identification of the principal dimensions of the feeling of pedagogical inclusion. Six SIP items were conceptualised in a 5-level Likert format. The resulting items were then validated using rigorous psychometric methods, including principal component analysis and Pearson correlation. The Pedagogical Inclusion Sentiment Scale (PIS) exhibits robust internal consistency, as evidenced by a high Cronbach's alpha coefficient ($\alpha = 0.83$), ensuring that items consistently assess the concept of inclusion. The factor analysis yielded two principal factors, which collectively accounted for 60% of the total variance.

School Inclusion Scale

In order to assess the Sense of School Inclusion Scale (SIS), a comparable methodology was employed to develop the SIS scale (Booth & Ainscow, 2002), which resulted in a 12-item, 5-level Likert scale. The SIS items were subjected to rigorous psychometric validation, employing principal component analysis and Pearson correlation. A high Cronbach's alpha coefficient ($\alpha = 0.85$) indicates strong internal consistency, thereby guaranteeing that the items reliably measure the concept of school inclusion. The results of the factor analysis indicate the presence of three principal factors, which collectively account for 65% of the total variance.

Statistical Analysis

All the variables studied were summarised using descriptive analyses. A one-factor ANOVA variance test was then performed to compare the pre- and post-tests of the variables related to feelings of inclusion, psychological well-being and self-esteem, and a percentage change was calculated using the formula (post-test-previous)/previous *100 if the difference between the pre- and post-tests was significant. A Bonferroni-corrected repeated measures ANOVA test was then performed to compare the effects of each pair of variables between the three groups (control, EPA, EPA+ para-athletes). Finally, a Pearson correlation test was performed to assess the strength of the relationships between the variables studied.

Results

This section presents a three-stage analysis. Firstly, the study presents descriptive data, including the mean and standard deviation of SPI, SSI, psychological well-being and self-esteem, before and after the implementation of the experimental protocol. Subsequently, the study analyses the observed variations between the three groups of participants, both before and after the intervention. Finally, the study examines the nature of the correlations between the different variables measured.

Evolution of educational inclusion and psychological variables

Table 1 shows the comparative analysis of the effects of three different interventions on parameters related to educational inclusion and psychological variables. The control group showed no significant change in any of the variables studied. However, there was a significant decrease in SIP (-14 %, $p = .004$). The Adapted PE group demonstrated notable enhancements in a number of variables. There was a statistically significant increase in self-esteem ($p < .000$), autonomy ($p = .009$), and environmental mastery ($p = .000$) by 3.25 %, 2.775 %, and 4.151 %, respectively. Furthermore, there was a notable increase in personal growth, with a 3.432 % increase ($p = .002$). The group that benefited from the combination of Adaptive PE and Para-Athletics demonstrated significant improvements in nearly all measured dimensions. There was a statistically significant increase in self-esteem ($p < .000$), with a mean change of 3.73 %. Additionally, there were notable improvements in autonomy ($p < .000$) and environmental mastery ($p < .000$), with mean changes of 7.646 and 8.824, respectively. Furthermore, this group demonstrated noteworthy enhancements in their positive

Table 1. Evolution of pedagogical and school inclusion, self-esteem and psychological well-being before and after intervention

Variables	Experimental protocol											
	Control (n=33)			p	APE (n=31)			p	APE+ Para-Athletics (n=32)			p
	Before	After	F		Before	After	F		Before	After	F	
SPI	3.57±0.65	3.07±0.71	8.862	.004	3.68±0.83	3.98±1.04	1.098	.299	3.83±0.70	4.69±0.40	27.866	.000
SSI	2.82±0.59	2.84±0.62	0.041	NS	3.29±0.63	3.82±0.87	3.328	.073	3.30±0.52	4.40±0.54	59.257	.000
Self-Esteem	1.98±0.45	2.04±0.47	0.057	NS	2.19±0.42	3.25±0.58	66.852	.000	2.25±0.50	3.73±0.50	139.932	.000
P-WB Autonomy	2.18±1.40	2.18±1.40	0.000	NS	4.16±1.44	5.39±1.84	-2.775	.009	4.16±1.74	6.50±0.76	-7.646	.000
P-WB Environmental mastery	2.88±1.49	2.76±1.54	0.318	NS	3.45±1.52	5.42±1.96	-4.151	.000	3.72±1.53	6.31±0.78	-8.824	.000
P-WB Personal growth	2.27±1.26	2.52±1.25	-0.713	NS	2.81±1.64	4.42±2.00	-3.432	.002	3.03±1.75	5.34±1.45	-6.136	.000
P-WB Positive relations with others	2.48±1.52	2.21±1.27	0.727	NS	2.84±1.63	4.74±2.02	-4.077	.000	3.28±1.82	5.91±1.23	-7.501	.000
P-WB Purpose in life	2.73±1.86	2.48±1.44	0.643	NS	2.94±1.93	5.90±1.68	-7.178	.000	3.47±1.87	6.28±1.37	-6.378	.000
P-WB Self-acceptance	2.39±1.68	2.88±1.58	-1.174	NS	2.61±1.73	4.26±2.28	-3.437	.002	2.78±1.62	5.13±1.98	-5.850	.000

P-WB. Psychological well-being, All results are written as mean±standard deviation

interpersonal relationships (+7.501, $p < .000$) and personal growth (+6.136, $p < .000$).

Effects of programs on educational inclusion and psychological parameters

Tables 2 and 3 show the results of an analysis of variance (ANOVA) used to assess the impact of different interventions on key variables related to educational inclusion and psychological well-being. The results show that all variables show statistically significant differences between groups, with p-values below 0.05. For example, the "self-esteem" variable has an F-value of 84.026 with a p-value less than 0.001, indicating a statistically significant difference between groups. Similarly, autonomy and environmental mastery show substantial differences, with high F-values of 85.724 and 39.269, respectively, and p-values less than 0.001. These results underline the effectiveness of interventions, particularly those involving adapted physical education (EPA) and Para-Athletics, in improving participants' perception of inclusion and psychological well-being.

Relationship between educational inclusion parameters and psychological

The following table presents the correlation coefficients between a number of variables related to the field of educational inclusion and the construct of psychological well-being. The variables examined include the sense of pedagogical inclusion (SPI), the sense of school inclusion (SSI), self-esteem and various dimensions of psychological well-being, such as autonomy, environmental mastery, personal growth, positive relations with others, Purpose in life and self-acceptance. The results demonstrate a notable positive correlation between variables, with the majority of correlations exhibiting a high level of statistical significance ($p < 0.01$). For instance, self-esteem demonstrates robust correlations with SSI ($r = 0.711$, $p < 0.01$) and purpose in life

Table 2. Effect of programs on pedagogical and school inclusion, as well as on self-esteem and psychological well-being, according to the 3 intervention modes

Variables	ANOVA I				
	SC	df	Carré moyen	F	p
SPI	28.982	2	14.491	30.950	.000
SSI	36.161	2	18.081	49.165	.000
Self-Esteem	33.489	2	16.745	84.026	.000
P-WB Autonomy	367.354	2	183.677	85.724	.000
P-WB Environmental mastery	168.935	2	84.467	39.269	.000
P-WB Personal growth	109.262	2	54.631	22.360	.000
P-WB Positive relations with others	168.553	2	84.277	32.563	.000
P-WB Purpose in life	187.625	2	93.812	30.204	.000
P-WB Self-acceptance	57.293	2	28.646	7.804	.001

SC. Sum of Squares Type III, P-WB. Psychological well-being, SPI. Sense of Pedagogical Inclusion, SSI. Sense of school inclusion, NS. Not Significant, Significant $p < .05$

Table 3. Pairwise comparison of variables on pedagogical and school inclusion, self-esteem and psychological well-being according to the 3 intervention modes

Variables	Control (n = 33)		APE (n = 31)		APE+ Para-Athletics (n = 32)	
	APE	APE+ Para-Athletics	Control	APE+ Para-Athletics	Control	APE
SPI	.000	.000	.000	.002	.000	.002
SSI	.000	.000	.000	.020	.000	.020
Self-Esteem	.000	.000	.000	.003	.000	.003
P-WB Autonomy	.000	.000	.000	NS	.000	.000
P-WB Environmental mastery	.000	.000	.000	NS	.000	.000
P-WB Personal growth	.000	.000	.000	NS	.000	.000
P-WB Positive relations with others	.000	.000	.000	.019	.000	.019
P-WB Purpose in life	.000	.000	.000	NS	.000	.000
P-WB Self-acceptance	.000	.001	.000	NS	.001	.001

P.WB. Psychological well-being, SPI. Sense of pedagogical inclusion, SSI. Sense of school inclusion, ** Very Significant ($p < .01$), * Significant ($p < .05$)

($r = 0.632$, $p < 0.01$), suggesting that elevated levels of school integration and well-defined Purpose in life are associated with enhanced self-esteem. Moreover, autonomy is significantly correlated with environmental mastery ($r = 0.833$, $p < 0.01$), indicating that individuals who perceive themselves as autonomous tend to also perceive a high level of control over their environment. Moreover, the correlations illustrate the interconnectivity of the diverse dimensions of psychological well-being, emphasising the comprehensive scope of these concepts.

Discussion

The findings of this study underscore the significant impact of adapted physical education (APE) in conjunction with para-athletics on the development of mental skills in students with motor impairments. It is noteworthy that participants in both APE and para-athletics programmes demonstrated improvements in skills such as stress management, self-confidence and concentration. These findings lend support to the proposition that engagement in structured physical activities serves as an efficacious conduit for the cultivation of psychomental skills, which are indispensable for navigating the quotidian challenges faced by these young individuals (Bouchard et al., 2012; Donnelly et al., 2016). Moreover, the findings of this study are in alignment with those of previous research, which demonstrate that when physical activities are tailored to the specific requirements of students, they not only enhance their physical abilities but also have a considerable impact on their mental well-being (Shields & Synnot, 2016). The results of recent research also corroborate these findings, indicating that APA is an effective method for reducing anxiety symptoms in young people with special educational needs (Anker et al., 2024). The results corroborate the psychosomatic and cognitive benefits observed in the aforementioned study.

The participants displayed enhanced concentration, particularly those involved in para-athletics. The capacity to sustain attention and focus on particular tasks is of paramount importance, not only in the context of sporting activ-

Table 4. Correlation matrix for variables relating to pedagogical and school inclusion, self-esteem and psychological well-being

Variables	1	2	3	4	5	6	7	8	9
1 SPI	1								
2 SSI	.603**	1							
3 Self-Esteem	.542**	.711**	1						
4 P-WB Autonomy	.592**	.463**	.580**	1					
5 P-WB Environmental mastery	.552**	.408**	.505**	.833**	1				
6 P-WB Personal growth	.434**	.392**	.459**	.565**	.565**	1			
7 P-WB Positive relations with others	.440**	.345**	.485**	.659**	.587**	.626**	1		
8 P-WB Purpose in life	.442**	.547**	.632**	.672**	.636**	.498**	.532**	1	
9 P-WB Self-acceptance	.319**	.275**	.305**	.383**	.253*	.476**	.419**	.244*	1

P.WB. Psychological well-being, SPI. Sense of pedagogical inclusion, SSI. Sense of school inclusion, ** Very Significant ($p < .01$), * Significant ($p < .05$)

ities, but also with regard to academic achievement and the effective management of daily activities (Camacho-Morles et al., 2021). Prior research has indicated that regular participation in a sport, particularly when adapted to the individual's abilities, is associated with enhanced attention regulation and increased concentration (Hut et al., 2023; Vaughan & Laborde, 2021; Zimmerman, 2006). The aforementioned cognitive abilities facilitate more effective navigation of often challenging school environments, thereby enabling the realization of full academic potential (Camacho-Morles et al., 2021). The findings of this study serve to reinforce the argument that APE and para-athletics programs confer benefits upon students in a number of ways. In addition to promoting physical development, these programmes have been demonstrated to markedly enhance students' cognitive abilities.

A further central aspect of this study is the significant improvement in the sense of pedagogical and school inclusion among students participating in EPA and para-athletics programmes. A notable difference was observed in the participation of BEP students in physical sports activities, as evidenced by one study (Ben Rakaa et al., 2024b). Furthermore, the perceptions of the students' teachers and their sense of pedagogical competence play a pivotal role in determining whether these students are integrated into the classroom (Ben Rakaa et al., 2024c, 2024a). The enhanced feeling of inclusion observed in this study is of the utmost importance for students with motor impairment, who frequently encounter physical, social and pedagogical obstacles that restrict their active involvement in the conventional school environment (Sammon et al., 2020). The findings of this study suggest that students in the experimental groups, particularly those engaged in para-athletics, not only reported a heightened sense of acceptance from their peers but also exhibited enhanced inclusion within the school community (Prince & Hadwin, 2013). This sense of inclusion extends beyond mere physical presence in the classroom and encompasses active and meaningful participation in educational activities, which is vital for the emotional and social well-being of students with impairment (Organization World Health, 2003). The findings of a recent study have confirmed that students with MD have experienced an improvement in their interpersonal relations and a greater sense of belonging (Prince & Hadwin, 2013).

The observed correlations between mental abilities and the feeling of being included in school serve to highlight the importance of LFS and para-athletics programmes for the overall well-being of students with motor impairment. The results demonstrate a significant correlation between enhanced self-confidence and commitment – two pivotal skills for academic and personal success – and an improved perception of academic inclusion (Prince & Hadwin, 2013). The enhancement of these skills provides students with the requisite tools to effectively navigate the social and academic challenges they encounter, thereby optimising their overall educational experience and long-term success (Song & Song, 2023). Furthermore, recent research findings suggest that APA programmes incorporating competitive elements, such as para-athletics, have a notable impact on enhancing students' psychosocial abilities (Puce et al., 2023). The results corroborate our findings and underscore the necessity of integrating these interventions into educational systems to advance global school inclusion, as evidenced in our study.

Furthermore, the findings of this study underscore the potential benefits of integrating APE with competitive sports such as para-athletics. This integration could enhance the development of mental skills and promote educational inclusion at both pedagogical and school levels. The combined APE + school para-athletics programme demonstrated the most substantial improvements in students, indicating that the integration of inclusive competitive sports is an efficacious approach to developing skills such as resilience, goal setting and mental preparation (Martín-Rodríguez et al., 2024; Weinberg & Gould, 2023). Furthermore, research indicates that competitive sports offer students with MD particular opportunities to challenge themselves, expand their abilities and improve their self-confidence while facilitating greater social inclusion (Ballas et al., 2022). This perspective is corroborated by evidence indicating that competitive sports, when adapted to the needs of MD students, have a significant positive impact on their general well-being and engagement at school (Shapiro & Martin, 2014).

Inclusion in EPA and para-athletics programmes also appears to have long-term effects on psychological well-being, as evidenced by improvements in stress management and control of distractions. Such abilities facilitate the reconciliation of academic expectations with the obstacles associated with the disability (Camacho-Morles et al., 2021). The results demonstrate that these programmes provide a structured and supportive environment in which students can not only enhance their physical capabilities but also cultivate effective strategies for managing stress and distractions, which are essential for their academic success. This observation is corroborated by previous research, which also confirms that interventions combining physical activity with clear goals and high expectations are particularly effective in developing resilience and stress management skills in young people with impairment (Shields & Synnot, 2016). Furthermore, recent research has demonstrated the long-term advantages of structured physical activity programmes, which not only enhance physical health but also foster psychological resilience and improve academic performance (Andermo et al., 2020).

Conversely, this study underscores the significance of APE and para-athletics in the advancement of physical capabilities and their indispensable function in fostering the mental and social well-being of students with motor impairment. The results demonstrate that these interventions should be regarded as indispensable components of any strategy designed to facilitate school inclusion and enhance the quality of life of students with special educational needs. The implications of these results are significant and suggest that schools should integrate APE and para-athletics programmes into their curricula in a more systematic manner in order to optimise the benefits for all students, particularly those with mobility impairments.

Conclusions

The findings of this study demonstrate the significant impact of adapted physical education (APE) programmes and inclusive school sports on the perception of pedagogical and school inclusion, psychological well-being and self-esteem among students with motor impairment. The results demonstrate that students who engage in these programs exhibit notable enhancements in these domains when

compared to those who attend conventional physical education classes. The results of the statistical analyses indicate that interventions combining APE and para-sport activities are particularly effective in improving self-esteem, feelings of inclusion and various dimensions of psychological well-being, including autonomy, mastery of the environment and positive relations with others. Such programmes facilitate not only better inclusion in the school environment for these students, but also contribute to their personal development and general well-being. The study, therefore, emphasises the necessity to maintain and extend these inclusive methodologies, which appear to be fundamental instruments for enhancing the quality of life and social inclusion of pupils with motor impairment. The results therefore indicate the necessity for a more comprehensive integration of adapted physical activity and para-sport into school curricula, with the objective of facilitating more efficacious school inclusion and enhanced psychological well-being for these young individuals.

Although the present study focused on a three-month period, existing literature suggests that the improvements observed in psychological well-being and sense of inclusion may persist beyond the intervention period, provided students continue to participate in adapted physical activities. Further research is required to test this hypothesis. In the Moroccan context, where the infrastructure for inclusive education is still under development, the integration of adapted physical activity plays a pivotal role in enhancing physical abilities and eliminating residual social and educational obstacles. The Moroccan experience offers a valuable case study that illustrates how inclusive education programmes can be adapted to overcome the aforementioned challenges. In order to optimise the effectiveness of APA programmes, it is recommended that educational establishments implement a system of ongoing training for educators on the most effective methodologies for inclusion. Furthermore, the involvement of parents in the process, for instance through their attendance or participation in particular activities, can serve to reinforce the student's commitment and foster a favourable environment within the home.

Conflict of Interest

If the authors have any conflicts of interest to declare.

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Сприяння інклюзії та благополуччю через інклюзивне фізичне виховання та параспорт: Застосування підходу щодо підлітків з порушеннями моторики

Омар Бен Ракаа[1ABCD], Мустафа Басірі[1ABCD], Саід Лотфі[1ABCD]

[1]Університет Хасана II в Касабланці

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

Реферат. Стаття: 9 с., 4 табл., 47 джерела.

Мета дослідження. Мета дослідження полягала у вивченні впливу залучення учнів з порушеннями моторики (ПМ) до адаптованого фізичного виховання (АФВ) та шкільної параатлетики на їхнє відчуття інклюзії в педагогічному та шкільному середовищі, а також на їхнє психологічне благополуччя та самоповагу.

Матеріали та методи. У дослідженні взяли участь 96 учнів віком 16,79 ± 0,87 років, які мають порушення моторної функції та навчаються в державних школах Марокко. Учнів було розподілено на три групи відповідно до параатлетичної класифікації: 30 % (сімейство з 30), 40 % (сімейство з 40) та 30 % (сімейство з 50). Учасників дослідження розподілено за методом рандомізації на три групи: контрольна група без спеціальної програми; група, яка займалася за програмою АФВ (24 заняття); а також третя група, яка виконувала програму АФВ та додаткові заняття з параатлетики (24 заняття), включаючи змагання впродовж трьох місяців. Проведення оцінювання здійснювалося на етапах перед- та постінтервенційного періодів. Для визначення рівня самоповаги, психологічного благополуччя, а також відчуття інклюзії в педагогічному та шкільному середовищі використовували відповідні шкали.

Результати. Отримані дані свідчать про поліпшення відчуття інклюзії в педагогічному та шкільному середовищі, психологічного благополуччя та самоповаги в учнів, які залучалися до програм АФВ та параатлетики, порівняно з контрольною групою. Група, яка брала участь як у заняттях з АФВ, так і в параатлетиці, продемонструвала найбільш значний прогрес за результатами цього дослідження.

Висновки. Представлені результати дозволяють стверджувати, що систематична інтеграція адаптованого фізичного виховання та інклюзивного спорту, зокрема параатлетики, до шкільних навчальних програм є ключовим елементом у сприянні інклюзії, благополуччя та самоповаги серед учнів з порушеннями моторики.

Ключові слова: інвалідність внаслідок порушення моторики, психосоціальний розвиток, освітня рівність, стратегії шкільної інклюзії, адаптовані види спорту, адаптована фізична активність.

Information about the authors:

Ben Rakaa, Omar: omarbenrakaa@gmail.com; https://orcid.org/0000-0002-2181-5247; Multidisciplinary Laboratory in Education Sciences and Training Engineering (LMSEIF), Sport Science Assessment and Physical Activity Didactic, Normal Higher School (ENS-C), Hassan II University of Casablanca, 19, Rue Tarik Ibnou Ziad, Casablanca 21100, Morocco.

Bassiri, Mustapha: m.bassiri@enscasa.ma; https://orcid.org/0000-0002-1077-8057; Multidisciplinary Laboratory in Education Sciences and Training Engineering (LMSEIF), Sport Science Assessment and Physical Activity Didactic, Normal Higher School (ENS-C), Hassan II University of Casablanca, 19, Rue Tarik Ibnou Ziad, Casablanca 21100, Morocco.

Lotfi, Said: lotfisaid@gmail.com; https://orcid.org/0000-0002-0008-6145; Multidisciplinary Laboratory in Education Sciences and Training Engineering (LMSEIF), Sport Science Assessment and Physical Activity Didactic, Normal Higher School (ENS-C), Hassan II University of Casablanca, 19, Rue Tarik Ibnou Ziad, Casablanca 21100, Morocco.

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Developing a Variation Index for Understanding Step Characteristics in the Long Jump Approach Run

Ankur Jyoti Phukon[1BCD] and Krishnendu Dhar[2ACD]

[1]Tripura University

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Corresponding Author: Krishnendu Dhar, e-mail: kdhartu@gmail.com
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Abstract

Objectives. The prime objective of the study was to develop a new variation index that can be used to identify the mechanical variations in the step pattern of the approach run.

Materials and methods. Twelve national-level long jumpers (age 19 ± 0.32 years) were analyzed in this study. Five high-speed action cameras with a resolution of 1920 x 1080 pixels at 120 frames per second were used. The data obtained were digitized with Quintic Motion Analysis software (v.33). In order to construct a Variation Index, the method of partial least squares structural equation modeling (PLS-SEM) was used. Additionally, a Principal Component Analysis (PCA) was applied to construct latent variable for the PLS-SEM.

Results. The results of the study revealed that step variation was started at the last 5th step of the approach run. Moreover, mechanical variation was observed among the last three steps of the approach run. These findings suggest that mechanical preparation for the final take-off in the long jump might start during the middle phase of the approach run.

Conclusions. The Variation Index introduced in this study offers a detailed understanding of an individual's approach run technique. Coaches and athletes can use this information to implement precise training strategies for optimizing the preparation for the final take-off during the approach run.

Keywords: biomechanics, principal component analysis, PLS-SEM method, motion analysis, latent variable.

Introduction

The variation index introduced in this study is based on the Partial Least Squares Structural Equation Model (PLS-SEM). This study draws substantial inspiration from the work of Oliva-Lozano et al. (2024), who developed a similar synthetic index. Cefis and Carpita (2024) have also showed the applicability of the PLS-SEM model within the games and sport. The current study also like to acknowledge the work of Crocetta et al. (2021) for their valuable contributions in illustrating various approaches to constructing the PLS-SEM model under different conditions. In this study, we apply these established methods specifically to track and field events, exploring a new perspective within this domain. To our knowledge, this approach offers a unique application in track and field, contributing a novel angle to the field of sports analytics.

The approach run in long jump is a crucial phase that determines the athlete's jump performance (Linthorne, 2006). In order to achieve maximum jumping performance, athletes must have precise control over their speed, stride length and stability throughout the approach during the appraoch run (Linthorne et al., 2005). In the field of sports, slightest mechianincal variations in thestep pattern of the appraoch run can have significant impact on take-off Phase (Linthorne et al., 2005). Çetin, Özdemir, and Özdöl (2014) highlighted the kinematic differences in stride lengths among jumpers, showing that the last four strides are particularly influential on the jumper's transition to take-off (Çetin et al., 2014). As irregularities might disrupt momentum and reduce jump effectiveness, optimal velocity and controlled step regulation require (Yoshida et al., 2018). Ghareb et al. (2016) found that ground reaction force management during the approach might enhance the ability to transfer the generated force to vertical direction as well. This is critical to achieving a smooth transition during the flight phase (Ghareb et al., 2016). In the year 1985, Hay and Miller observed that elite athletes utilize specific techniques to control stride length

and body posture, which maximizes kinetic energy transfer at take-off. Similarly, Theodorou et al. (2017) identified asymmetries in the approach stride as a factor that can impact take-off efficiency. The result of the study suggested that even minor adjustments in approach run can create considerable alteration in the long jump performance (Theodorou et al., 2017). Addressing these biomechanical changes might lead to more refined techniques for optimizing approach mechanics, potentially offering competitive advantages (Hay & Miller, 1985b). This understanding not only benefits coaches in training elite jumpers but also serves as a foundation for early stages of training (Graham-Smith & Lees, 2005; McCosker et al., 2021; Scott et al., 1997).

Research on the approach phase in long jump highlights key biomechanical and performance factors that impact overall jump distance (Panoutsakopoulos et al., 2010). Studies reveal that athletes make precise adjustments in stride length and approach velocity prior to the final take-off step (Çetin et al., 2014). this adjustment might play a pivotal role in maximizing jump distance (Çetin et al., 2014). These adjustments are not random; they are deliberate actions by the athlete to control the balance of both speed and precision for optimal performance (Çetin et al., 2014). Furthermore, their (Çetin et al., 2014) findings also suggest that the transition from approach to take-off requires careful regulation of step length and the position of the centre of mass. Step regulation in the approach run directly affects the efficiency of kinetic energy transfer (Bridgett & Linthorne, 2006). Elite athletes distinguish themselves through biomechanical alterations in the control of approach speed, balance and body positioning, setting them apart from less experienced jumpers (Hay & Miller, 1985a). Additionally, the relationship between preparation steps and ground reaction forces highlights the importance of force management in the last few steps. It might enable athletes to approach the take-off angle with optimal speed and control, enhancing performance and minimising take-off errors (Ghareb et al., 2016). Step symmetry is also found to play a crucial role, as irregularities can disrupt momentum, impacting jump distance (Panoutsakopoulos et al., 2021). Maintaining symmetry in the step regulation in the approach run might results in improved jump performance (Theodorou et al., 2017). It offers a technical advantage for athletes at all skill levels (Theodorou et al., 2017). On the other hand, Rhythm in the approach phase is equally significant (Yoshida et al., 2018). A consistent rhythm allows for a smooth transition from the run-up to take-off. As a result athletes are able to regulate gait patterns and maintain stable speed control, critical for setting up a powerful and stable take-off (et al., 2018).

The preparation for the final take-off during the approach is been a critical area of concern for sports scientists, coaches and athletes. Most of the studies have primarily highlighted the mechanics of the final steps before the take-off phase (Çetin et al., 2014; Panoutsakopoulos et al., 2010; Scott et al., 1997; Theodorou et al., 2017). Some of the studies have attempted to understand the mechanical characteristics and showed mechanical characteristics of these final steps significantly influence the take-off and overall jump distance (Graham-Smith & Lees, 2005). The mechanical changes, especially in the last phase of the approach, also help in minimizing errors before the final step, aiming to stabilize the athlete's position for take-off (Jaitner et al., 2001; Shimizu et al., 2018). However, while the mechanics of the three steps are well-studied, there is limited research on the mid-phase of the approach run, which could offer insight into the earlier preparatory adjustments that support the final take-off phase. A smoother transition between the mid-phase and the last steps might exist to optimise take-off mechanics (Graham-Smith & Lees, 2005; Lees et al., 1994). Past studies indicates that sudden mechanical changes are unlikely to occur solely in the final phase; instead, it might initiate in the mid-phase of the approach run, a area largely absent from existing literature (Shimizu et al., 2018; Zhang, 2016). Latest innovation and advancements in sports science and technology have enabled more precise analyses of long jump mechanics (Alexander, 1990; Graham-Smith & Lees, 2005). However, these methods often require costly, high-tech laboratory environments that may be inaccessible to grassroots athletes and amateur practitioners (Jaitner et al., 2001). To address this limitation, developing a theoretical model based could be very much useful for the coaches and athletes at all levels. This might create a practical, accessible framework for training and performance optimization without the need for expensive equipment.

In order to bridge up forementioned research gap, the prime objective of the current study was to introduce a variation index for last 10 step of the approach run. Secondly, the study also analysed each step to identify to mechanical changes during the approach run using the new variation index. This theoretical model that might be accessible for the coaches and athletes to understand the mechanical changes during the approach run. Coaches can identify the specific and individualized nature of the athlete to implant more precise training programme. Further, this theoretical model might be also applied for the better understanding the mechanical characteristics of the walking gait cycle and running gait cycle.

Materials and Methods:

The participants

The study comprised twelve (12) female Indian national-level long jumpers, with a mean age of 19 ± 0.32 years. All participants were finalists in the women's long jump event at the 22nd Junior Federation Athletic Championship 2023, held in Lucknow, Uttar Pradesh, India. Each athlete was capable of achieving jumps exceeding six meters, and they were purposively selected for the study. As data collection occurred during the official competition, no anthropometric data were collected. Formal permissions were obtained from the designated referee, technical delegates, and media manager before data collection. Consent was also obtained from the athletes and their coaches. This study received approval from the Research Advisory Committee of Tripura University, India.

Procedure for collecting data

A written consent were obtained prior to the data collection process. Each participant was allowed a maximum of six trials, only legal attempt was selected for analysis. The approach runs of the athletes were recorded using five

high-speed action cameras. All cameras were positioned in predefined locations to capture the entire approach run phase. The height of each camera was set between 1.00 meter and 1.20 meters from ground level, and the perpendicular distance from the runway to each camera's position ranged from 7 to 10 meters.

Tools and instruments used

Five high-speed action cameras (Go Pro Hero 11) were used to record the movements. All the cameras were set in linear mode for the recording. The movements were recorded with a resolution of 1920 × 1080 pixels at 120 frames per second. The camera height was fixed at 1.20 meters. The position of the cameras is presented in the following Figure (A). A calibration box of length 1 meter was used as a reference for the recorded videos. The calibration stick was first set in a perpendicular direction to the surface (x-axis) and then also set in parallel to the surface (y-axis). The calibration was done before each optical axis of the three cameras.

The recorded videos were subsequently digitized and analyzed using Quintic Motion Analysis software (v.33). A total of 21 two-dimensional body segments were digitized to enable linear data transformation. In order to determine intra-reliability, all the recorded movements were digitized twice with two different experienced individuals within two weeks. A total number of 55 officially successful jump attempts were analysed in this study.

Construction of the Variation Index

At first, we calculated the variation within each step based on the biomechanical parameters for all athletes. A correlation analysis was conducted to remove collinearity to introduce a new variation index. Further, a Principal Component Analysis (PCA) was performed as an exploratory analysis to identify primary factors within the biomechanical parameters for the index and to select the most relevant variables. As a result, 9 biomechanical parameters were selected from all three principal components. The analysis revealed three significant latent components (eigenvalues greater than 1) that accounted for approximately 83 % of the original variability. For each latent component, variables with a loading factor of $|\lambda| > 0.65$ were selected following a varimax rotation. In total, 9 variables closely associated with their respective components (see Table 1) were chosen.

The Variation Index created using biomechanical parameters through a stepwise approach. Due to the nature of the data, the PLS-SEM method, a non-parametric approach, was chosen. A hierarchical Second-Order PLS-SEM model was employed to consolidate multiple biomechanical parameters into a single composite index. The model was executed using smartPLS (version 3.3.7) and the R package seminR (version 2.3.2), with 3000 bootstrap resamples performed for result validation. The process followed the Mixed Two-Step approach, starting with the estimation of lower-order constructs, which were then utilized to compute the higher-order construct, the Variation Index.

The index is constructed using three components based on biomechanical parameters identified by the Principal Component Analysis. Component 1 includes the Maximum Amortization Angle (MA), the Height of the Center of Mass (CM) during the Maximum Amortization Angle (MAH), the Height of the CM during the initial contact of the foot with the ground (TDH), and the Height of the CM during the initial touch-off of the foot from the ground (TOH). Component 2 consists of the Maximum Amortization Angle (MA), Step Length (SL), and the Contact Duration of the foot with the ground (CD). Lastly, Component 3 comprises the Touch-Down Angle of the Center of Mass (TDA) and the Touch-Off Angle of the Center of Mass (TOA). In order to calculate the index for step number 'n' with 9 biomechanical parameters, the following derivations were done(based on the weights w of Figure 1). The first latent component is derived from the first principal component, while the second and third latent components are derived from the second and third principal components, respectively.

Firstly, three latent components are calculated for each nth step of the approach run.

Latent Component 1_n = $(1.087 \times MA_n) + (-0.812 \times MAH_n) + (0.492 \times TDH_n) + (0.069 \times TOH_n)$

Latent Component 2_n = $(0.499 \times MA_n) + (0.123 \times SL_n) + (0.548 \times CD_n)$

Latent Component 3_n = $(-0.383 \times TDA_n) + (0.777 \times TOA_n)$

[Each step is represented by n, where, n = 1, 2, 3,…9,10]

Finally, with these three latent components, the Variation index is now calculated as follows

Variation Index = $(0.0174 \times \text{Latent component } 1_n) + (0.526 \times \text{Latent component } 2_n) + (0.105 \times \text{Latent component } 3_n)$

Structural equation Modelling Analysis

The calculated variation index in this study represents the relationship between the mechanical variation of the approach run in each step. The score of composite reliability is 0.957, which more than 0.70. This indicates the trustworthy of the current model (Hair & Alamer, 2022). Fruther more this score of the cronbach's Alpha (0.911), which shows that calculated index in reliable and and are abopve the required value of 0.60 (Hair & Alamer, 2022). This is also supported by the score of Average Variance Extracted (AVE), which is also greater than 0.50 (table 1). The SRMR value of the model can describe if the variation index is fit for this study or not. According to the Hu & Bentler (1999) the SRMR value should be less than 0.10. As shown in the table 1 the current SRMR value is 0.080 <0.10. which indicates that model is appropriate for this study (Hu & Bentler, 1999).

Table 1. Measurements of the model estimation value and model FIT validity

Cronbach's Alpha	Rho-A	Composite reliability	Average Variance Extracted (AVE)	SRMR		R-Squared	
				Saturated model	Estimated model	R-square	R-square adjusted
0.911	0.911	0.957	0.918	0.080	0.080	0.774	0.661

Furthermore, the coefficient of the determination of the model or R-squared value indicates that the introduced variation index is influenced by 77.4 % from the included biomechanical variables in the present study.

Results

In this following section the result of the analysis is being discussed.

In the table 2, average score of the selected biomechanical parameters is mentioned. The average value of the selected biomechanical parameters starts from the last 10th step to last step that is final take-off step. All the measurements were mention according to the SI unit.

The table 3 represents the identified major components found as a result from the PCA analysis. The first Principal Component includes 4 biomechanical parameters namely, MA (Maximum Amortization Angle),MAH (Height of the CM during Maximum amortization Angle), TDH (Height of the CM during initial contact of the foot with ground) and TOH (Height of the CM during initial touch off of the foot from the ground). The first Principal Component explained more than 83% of the variation. In the second Principal components includes MA (Maximum Amortization Angle), SL (Step Length) and CD (ground contact duration). More over the third principal component was found with two mechanical parameters which are TDA (Touch down angle of the CM) and TOA (Touch off angle of the CM).

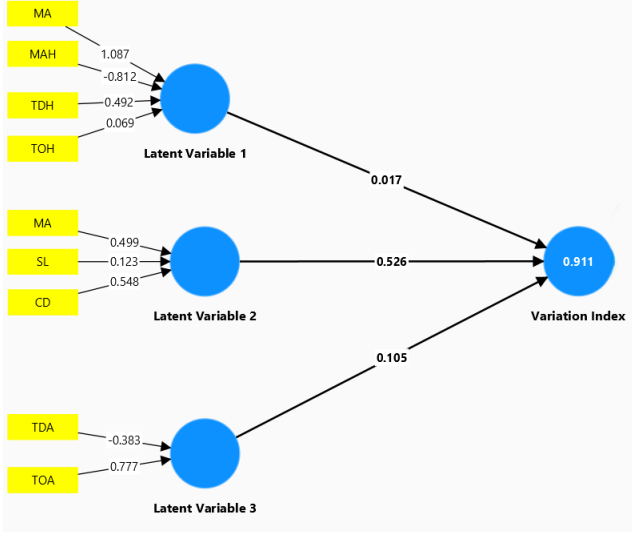

Fig. 1. Schematic diagram for calculating Raw Variation Index

In the figure 1, the three latent variable and its connection of the calculated variation index is represented with a schematic diagram.

In the table 4 calculated score for each three latent variables along with the variation index for the respective step is showed. In the last column of the table 4, difference

Table 2. Description of the selected biomechanical variables

Step number	CD (Sec)	MA (Degree)	TDA (Degree)	TOA (Degree)	SL (meter)	TDH (meter)	MAH (meter)	TOH (meter)
10	0.124	140.325	72.650	54.713	1.679	6.477	7.075	0.896
9	0.120	140.125	74.288	55.113	1.694	6.664	7.202	0.916
8	0.119	139.500	74.975	52.913	1.721	6.453	7.076	0.906
7	0.124	135.950	72.113	54.950	1.736	6.655	7.082	0.880
6	0.119	141.163	71.975	56.488	1.740	6.477	7.052	0.897
5	0.116	138.950	74.150	53.600	1.736	6.688	7.192	0.911
4	0.114	138.175	74.138	53.125	1.751	6.453	7.077	0.899
3	0.114	118.680	72.025	55.363	1.754	3.464	4.303	0.883
2	0.157	130.700	68.300	53.613	1.799	8.625	6.981	0.887
Final Take-off step	0.173	118.829	59.300	70.088	1.724	6.171	6.651	1.099

Table 3. Summarization of results from the Principal Component Analysis (PCA)

Component Name	Variables	Description of the variables
Component 1	MA	Maximum Amortization Angle
Component 1	MAH	Height of the CM during Maximum amortization Angle
Component 1	TDH	Height of the CM during initial contact of the foot with ground
Component 1	TOH	Height of the CM during initial touch off of the foot from the ground
Component 2	MA	Maximum amortization angle
Component 2	SL	Step length
Component 2	CD	Contact duration of the foot with ground
Component 3	TDA	Touch down angle of the CM
Component 3	TOA	Touch off angle of the CM

Table 4. Latent variables for each Phase

Steps Numbers	Latent Variables			Calculated variation Index	Difference between the index for respective steps
	L1	L2	L3		
10	1.397	1.402	0.304	1.281397	
9	0.702	0.609	0.262	0.581808	0.7
8	0.754	1.055	1.430	1.248548	0.67
7	3.623	1.539	0.775	1.419258	0.17
6	0.747	1.235	0.733	1.254895	0.16
5	0.585	1.241	0.698	1.25857	0
4	2.166	0.558	0.434	0.513	0.75
3	3.393	3.306	0.577	2.986758	2.47
2	3.538	2.059	0.854	1.912223	1.07
1	1.895	2.569	0.937	2.462679	0.55

between the variation index with the following index is displayed. It was found that the difference between the variation index is very low (less than 1) for the 9th, 8th,7th and for the 6th step respectively. However, the difference between the index is increasing from the last 5th step to the second last step (figure 2).

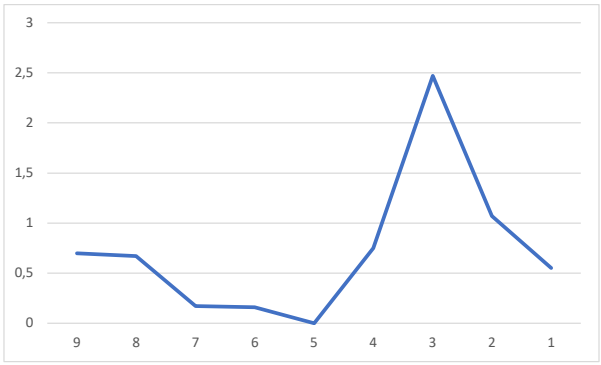

Fig. 2. Graphical representation of value of the difference between the index for respective steps

Discussion

Understanding mechanical variation of the long jump's approach run are the key factor for initiating final take-off phase. Introducing a Variation Index for the approach run might help our coaches and athletes to identify the potential biomechanical. The present study identified four key kinematic variables that collectively account for over 80% of the variation. These variables are Maximum amortisation angle (MA), Height of the CM during Maximum amortisation Angle (MAH), Height of the CM during initial contact of the foot with the ground (TDH) and Height of the CM during initial touch off of the foot from the ground (TOH). Secondly, the calculated index observed mechanical alteration among the step characteristics, especially in the mid phase of the approach run. Alteration in the mid phase of the approach might indicates earlier preparation prior to the final take-off step. The result of the study might provide coaches and athlete a better understanding of their approach technique in the long jump.

The result from the first Principal Component Analysis identified 4 biomechanical parameters. These parameters are MA, MAH, TDH and TOH and accounted for 83% of the total variation. The maximum knee flexion angle during swing phase allows efficient transition in the support phase. This increases both propulsive forces and step length of the running gait cycle (Mann & Herman, 1985). However, excessive knee flexion can extend ground contact time, decrease step frequency and eventually hinder performance (Maćkała et al., 2015). Similarly, a lower center of mass at touchdown provides more steady and efficient force application (Mann & Herman, 1985). Position of the low centre of mass might enhance acceleration during the approach run (Mann & Herman, 1985). On the other hand, Mattes et al. (2021) also showed that the angle of foot touchdown relative to the body's center of mass is vital for optimizing ground reaction force application while minimizing braking forces (Mattes et al., 2021). The current study also found that the maximum amortization angle (MA), Step length (SL) and Contact duration of the foot with the ground (CD) also explained a considerable variance in the approach run. Increased step lengths are generally associated with higher running velocities with optimal step frequency (step per second). As they enable the athlete to cover more distance in minimum time (Majumdar & Robergs, 2011). However, the balance between these two variables, step length (SL) & step frequency (SF), also plays an essential role in maintaining optimal velocity for the athletes. Elite sprinters may rely more on either SL or SF to reach peak velocity, highlighting the need to consider this variability in training programs (Bezodis et al., 2011; Salo et al., 2011). Athletes might adjust the SL-SF balance to maintain velocity with increasing SL and reducing SF during deceleration (Bezodis et al., 2011). Consequently, step frequency (SL) becomes an essential variable to achieve high running velocities. The duration of foot contact with the ground equally influences the capacity to generate propulsive forces in the approach run. As observed in elite sprinters, reduced contact times facilitate greater step frequencies, thus providing higher running velocities (Maćkała et al., 2015). The Principal Component Analysis (PCA) also identified the touchdown angle of the centre of mass (TDA) and take-off angle of the centre of mass (TOA) as important factors in maintaining optimal velocity during the approach run. The angles at which the foot strikes and leaves the ground are also crucial. A sharper touchdown angle, where the foot hits the ground at a more acute angle, helps facilitate the storage and release of elastic energy, improving running efficiency and velocity (Panoutsakopoulos et al., 2021). Similarly, a more acute take-off angle, where the foot leaves the ground, allows for a more efficient transition from braking to propulsion in the step cycle (Panoutsakopoulos et al., 2021; Theodorou et al., 2017).

The step variation index created in this study is very new approach to this field, within our knowledge. Though the mathematical calculations of this PLS-SEM structural model is an established approach in the sport field (Cefis & Carpita, 2024), but has yet to be applied for the identification for the step variation in the long jump approach run. This variation index is based on some of

the prime contributory factors that was computed in PCA. The variation index indicates the level of variation among the prime biomechanical contributory factors in each step of the approach run. On the other hand, the difference between the variation index denotes the level of variation in between two consecutive steps. The higher value of difference between the index indicates lower variation level in between the steps and vice versa. If the difference between the index for two consecutive steps is closer to the value of zero or equal to zero, meaning that those two consecutive steps is similar in nature. This might be very helpful to identify the variation among the steps to study the nature of the step characteristic. Figure 2 shows that from the last 10th step to the last 5th step, the variation among the steps is very similar. However, a drastic change is observed after the 5th steps (fig 2). It is observed that difference between the variation index is relatively higher specially in the last 4th, last 3rd, last 2nd and last steps (Take-off step) of the approach run. This might indicate that these steps are very much differs from the each other. They possessed unique mechanical characteristics for the last phase of the approach run. Additionally, the index value is found comparatively higher in the last 3rdstep. Past studies showed that initial preparation for the last 3rdstep is starts by slightly shortening step length and lowering the center of gravity (CG) (Panoutsakopoulos et al., 2021). This adjustment helps the athlete maintain horizontal velocity while beginning to prepare for the vertical lift needed for take-off (Hay & Nohara, 1990; Panoutsakopoulos et al., 2021). Controlling the velocity in this step is becomes crucial to make necessary adjustment in running cycle. Since excessive or insufficient adjustments might affect the effectiveness of the following steps (Çetin et al., 2014). It was observed that in athletes tends to lowers the CG with a slightly lengthened step in the second last step (Linthorne et al., 2005). This allows the athlete to adjust momentum while balancing horizontal and vertical components of the resultant momentum. Absorbing horizontal momentum creates the required stability for an optimal take-off position. It provides smooth transition to the final take-off phase (Béres et al., 2014). In the final take-off step, step length is shortened to maximize vertical adjustment and prepare the CG for the jump (Linthorne et al., 2005). This is essential for effective loading the take-off leg, allowing the athlete to apply maximum force against the ground (Kariyama et al., 2017). This helps to efficiently convert horizontal velocity into vertical lift, which is critical for jump distance (Theodorou et al., 2017). Together, all these adjustments in step length and CG positioning ensure a continuous and efficient transition into take-off phase.

The current study found that the variation of the last phase of the approach is begins from the last 5th step. This might be the earlier preparation for the take-off, where preliminary biomechanical adjustment begins. Initiating adjustments from the mid phase of the approach run highlights the importance of progressive biomechanical preparation before take-off (Panoutsakopoulos et al., 2021; Theodorou et al., 2017). Hay and Nohara (1990) in their study mentioned the preparation for the final take-off might begin several steps before the take-off board. It allows the athletes to manage their final approach velocity and body positioning for the final take-off. Adjusting key mechanical parameters such as step length, velocity, and positioning of the center of gravity (CG) etc. prior to the final take-off, collectively contribute for optimum momentum and take-off angle (Hay, 1988; Lees et al., 1994). This adjustment might be crucial for accurate foot placement on the take-off board for final take-off. Further, Bridgett and Linthorne (2006) mentioned that prior to the final take-off, athletes must carefully balance and maintain horizontal momentum to maximize jump distance. The mechanical adjustments from the mid approach phase might help athletes gradually regulate their step pattern for the final take-off. As a consequence, it reduces the risk of unexpected changes during last phase of the approach and enabling athlete for optimum execution of the final take-off phase (Arampatzis et al., 1999; Glize & Laurent, 1997).

This study has several limitations worth considering. Firstly, its observational nature excludes cause and effect relationship between biomechanical parameters and performance outcomes. The analysis relied solely on two dimensional kinematic data, which might be inadequate when compared to the three dimensional data. Additionally, the limited sample size and population may constrain the generalizability of the findings to a broader context. Using PCA and the newly developed "Step Variation Index" represents an innovative approach, which might need more replication and comparison with other established methods. Finally, the impact of biomechanical adjustments on performance may vary across different athlete skill levels and training backgrounds, which was not extensively explored in this study.

Conclusions

The study approached a new theoretical model to understand the approached run mechanics the long jump approach run. According to the objective of the study, a "variation index" is constructed based on the PLS-SEM model. As a result, this model identified that mechanical variation in the step characteristic exist in the mid phase of the approach run. This might be the preparation for the athlete before the last phase of the approach run in order to perform precise and controlled final take-off.

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Conflict of Interest

If the authors have any conflicts of interest to declare.

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Розробка індексу варіації щодо розуміння характеристик виконання кроків у стрибках в довжину з розбігу

Анкур Джйоті Пхукон[1BCD], Крішненду Дхар[1ACD]

[1]Трипурський університет

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

Реферат. Стаття: 8 с., 4 табл., 2 рис., 36 джерел.

Мета дослідження. Основна мета дослідження полягала в розробці нового індексу варіації, який можна використовувати для визначення механічних варіацій щодо структури кроків під час виконання розбігу.

Матеріали та методи. У цьому дослідженні проаналізовано дванадцять стрибунів у довжину національного рівня (вік 19 ± 0,32 року). Було використано п'ять високошвидкісних екшн-камер з роздільною здатністю 1920 × 1080 пікселів з частотою 120 кадрів на секунду. Отримані дані були оцифровані за допомогою програмного забезпечення для аналізу рухів спортсменів "Quintic Motion Analysis" (v.33). Для побудови індексу варіації застосовано спосіб моделювання структурними рівняннями за методом найменших квадратів — "Partial least squares structural equation modelling" (PLS-SEM). Крім того, застосовано метод головних компонент (МГК) з метою побудови латентної змінної для PLS-SEM.

Результати. За результатами дослідження встановлено, що варіація кроку починається на останньому 5-му кроці розбігу. Крім того, механічна варіація спостерігалася між останніми трьома кроками розбігу. Отримані дані свідчать про те, що механічна підготовка до фінального відштовхування у стрибках у довжину може починатися під час середньої фази розбігу.

Висновки. Індекс варіації, представлений у цьому дослідженні, надає детальне розуміння техніки індивідуального розбігу. Тренери та спортсмени можуть використовувати зазначену інформацію з метою впровадження чітких тренувальних стратегій щодо оптимізації підготовки до фінального відштовхування під час виконання розбігу.

Ключові слова: біомеханіка, метод головних компонент, метод PLS-SEM, аналіз рухів, латентна змінна.

Information about the authors:

Phukon, Ankur Jyoti: aphukon66@gmail.com; https://orcid.org/0009-0002-2545-8416; Department of Physical Education, Tripura University, NH8, University Rd, Suryamani Nagar, Agartala, Madhupur, Tripura 799022, India.

Dhar, Krishnendu: kdhartu@gmail.com; https://orcid.org/0000-0001-6283-7832; Department of Physical Education, Tripura University, NH8, University Rd, Suryamani Nagar, Agartala, Madhupur, Tripura 799022, India.

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Original Scientific Article

The Effect of a 12-Week Plyometric and Tabata Training Program with Three Weekly Sessions on Cardiovascular Efficiency in Elite Soccer Players

Nidhin Muthrathiparambil Narayanan[1ABCDE], Kayambu Sundar[1ABCDE], Nirmal Michael Salvi[2CDE], Yashpal[3CDE], Debajit Karmakar[4CDE], Sohom Saha[4CD], Bekir Erhan Orhan[5ACD], Farjana Akter Boby[6ACDE] and Yuni Astuti[7ACDE]

[1]Alagappa University
[2]Symbiosis International (Deemed University)
[3]Pt. Chiranji Lal Sharma Government College
[4]Lakshmibai National Institute of Physical Education
[5]Istanbul Aydin University
[6]Daffodil International University
[7]Universitas Negeri Padang

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

Corresponding Author: Yuni Astuti, e-mail: yuniastuti@fik.unp.ac.id
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Abstract

Objectives. This study aimed to examine the effects of a 12-week plyometric training program and a Tabata regimen on cardiovascular efficiency in elite soccer players.

Materials and methods. Sixty male inter-university players, aged 20.79 ± 1.75 years, were randomly assigned to the Plyometric Training Group (PTG, n = 20), Tabata Training Group (TTG, n = 20), or Control Group (CG, n = 20). Cardiovascular metrics, including vital capacity, resting heart rate, mean arterial blood pressure, breath-holding time, and respiratory rate, were assessed before and after the program. Both PTG and TTG completed three 90-minute sessions on a weekly basis.

Results. The results revealed that both the PTG and TTG showed significant improvements in cardiovascular efficiency. Vital capacity increased by 30.83% ($d = 1.24$, $p < 0.001$) in PTG and by 34.61% ($d = 1.52$, $p < 0.001$) in TTG. Resting heart rate decreased by 12.36% ($d = 1.74$, $p < 0.001$) in PTG and by 15.18% ($d = 1.82$, $p < 0.001$) in TTG. Breath-holding time increased by 29.86% ($d = 2.12$, $p < 0.001$) in PTG and by 34.42% ($d = 2.35$, $p < 0.001$) in TTG. Respiratory rate decreased by 28.07% ($d = 1.04$, $p < 0.001$) in PTG and by 28.33% ($d = 1.10$, $p < 0.001$) in TTG. These findings highlight the substantial positive impact of both training methods on cardiovascular efficiency in elite soccer players.

Conclusions. In conclusion, the implementation of a plyometric and Tabata training program has been found to produce significant improvements in cardiovascular efficiency in elite soccer players, making them valuable preseason conditioning strategies to enhance endurance, performance, and overall athletic abilities.

Keywords: soccer training, physiological parameters, HIIT, jumping training, football players.

Introduction

Athletes must meet high physical demands in football, especially in terms of cardiovascular endurance, because the sport is characterized by intermittent outburst of speed, direction changes, and endurance (Carling et al., 2012; Radaković et al., 2024; Stolen et al., 2005). It is necessary to keep player's cardiovascular system in top condition, as that is crucial for the best performance possible from soccer players on the ground (Bush et al., 2015; Nystoriak & Bhatnagar, 2018; Radaković et al., 2024). In light of the importance of cardiovascular health in football, several training strategies

have been developed to increase it, with plyometric training and high intensity interval training (HIIT), including Tabata, considered as two of the most efficient measures considering their benefits (Afyon et al., 2021; Tabata, 2019; Thomakos et al., 2023). The logical combination of plyometric training with high-intensity interval training (HIIT) has been widely researched and discussed as an effective methodology to enhance athletic performance, more specifically in what cardiovascular capacity is concerned (Davies et al., 2015; Fajrin et al., 2018; Kons et al., 2023; Martin-Smith et al., 2020). Significantly, they have been proven efficient to enhance both aerobic and anaerobic capacities of athletes across different disciplines such as football (Hostrup & Bangsbo, 2023; Keren & Epstein, 1981; Yan et al., 2022). However, despite the considerable amount of literature on each method separately, a direct comparative evaluation between these two methods on cardiovascular efficiency in elite football players is still scarce and was the subject of this study. Plyometric training, characterized by explosive and power-driven movements including jumps, bounds, and rapid directional changes, has been extensively documented regarding its beneficial impacts on athletic performance (Kons et al., 2023; Sinkovic et al., 2023).

Plyometric training has several merits, such as improvement in muscular power and favourable effects on resting heart rate and blood pressure (Deng et al., 2024; Ramírez-Campillo et al., 2015). It makes sense when Faigenbaum et al. (2007) writes, "Athletes also demonstrate decreases in resting heart rate and improvements in blood pressure control following plyometric training suggesting substantial cardiovascular adaptations. These findings have importance in particular for football players, who need to keep a high resistance of the cardiorespiratory system in order to respect the physical demands of a game (Faigenbaum et al., 2007). Despite these findings, the impact of plyometric exercise on a wide range of cardiovascular parameters, such as vital capacity and respiratory rate, has received little attention, particularly among professional football players (Singh et al., 2024; Singh et al., 2021).

As a type of high-intensity interval training, Tabata training is designed to be one of the quickest way to improve aerobic and anaerobic parameters. The regimen was introduced by Tabata et al. (1996) comprises of brief high-intensity exercise intervals followed by minimize recovery times. According to the study, athletes on Tabata training quadratically improved their VO2 max (a key indicator of cardiovascular health and overall fitness) within a matter of weeks (Tabata, 2019). There are many studies that have been conducted to investigate the benefits of Tabata training, which has been found to improve CV fitness, lower resting HR and even decrease blood pressure (Milanović et al., 2015). Lu et al. (2023) revealed that Tabata-style HIIT enhanced cardiovascular capacity alongside energy efficiency, meaning that competing athletes would be able to support high-intensity exercise with less of a cardiovascular drain (Lu et al., 2023). This is important for football players, as they have to consistently play sprints at high intensity and recover fast during games. Despite the large increase in VO2max associated with this type of exercise, most studies have employed an intensity that is far from what has been called the maximal production or power output and closely oriented to football training practice (Sloth et al., 2013).

Though plyometric and Tabata training have been extensively researched, there is a striking lack of studies explicitly evaluating their effects on cardiovascular efficiency in football players. Previous studies have usually focused on specific aspects of cardiovascular fitness, such as VO_2 max or heart rate, while failing to examine a comprehensive set of cardiovascular indicators that could provide a more complete knowledge of cardiovascular efficiency (Granero-Gallegos et al., 2020; Vesterinen et al., 2016). Furthermore, the enduring impacts of these training modalities, especially within a soccer-specific framework, have yet to be thoroughly investigated. Investigations often focus on short-term interventions; however, there is a paucity of knowledge regarding the impact of prolonged programs, extending 12 weeks or more, on both aerobic and anaerobic systems in elite athletes.

Although the current body of research emphasizes the advantages of plyometric and Tabata training concerning different facets of physical performance and cardiovascular fitness, the direct comparison of these training modalities in elite football players has not been thoroughly investigated. Furthermore, the incorporation of various cardiovascular markers, including vital capacity, breath-holding time, and respiratory rate, in existing studies is limited. Thus this research seeks to address the existing gap by exploring the effects of plyometric and Tabata training on cardiovascular efficiency in football players over a 12-week duration, thereby contributing valuable insights into the enhancement of training protocols for elite athletes.

Materials and Methods

Participants

This investigation involved sixty participants, consisting of young adult male elite soccer players, with a mean age of (20.73 ± 1.83 years) for the Plyometric Training Group (PTG), (20.80 ± 1.69 years) for the Tabata Training Group (TTG), and (20.85 ± 1.72) years for the Active Control Group (ACG). Participants were recruited from Kerala State.

Inclusion and Exclusion Criteria

All participants were categorized as inter-university level players with a background of systematic soccer training averaging 3.6 ± 2.4 years, with three to five training sessions per week required for participation. It is important to note that all individuals were in good health and had no history of significant musculoskeletal injuries in the six months prior to the start of the research. Participants who missed more than 20% of the total training sessions or two consecutive sessions were excluded from the study.

Study Design

Participants were randomly allocated to one of three groups: Plyometric Training Group (PTG) (n = 20; age = 20.36 ± 2.45 years; weight = 71.26 ± 4.32 kg; height = 171.25 ± 7.16 cm), Tabata Training Group (TTG) (n = 20; age = 20.75 ± 3.17 years; weight = 72.37 ± 2.24 kg; height = 170.36 ± 3.37 cm), and Active Control Group (ACG) (n = 20; age = 20.79 ± 3.54 years; weight = 72.49 ± 3.57 kg;

height = 172.12 ± 2.14 cm). The anthropometric details for all groups can be found in Table 1. The study was guided by the most recent version of the Declaration of Helsinki, ensuring compliance with approved ethical standards for research in sport and exercise science.

Table 1. Participant's demographic of the 3 groups (PTG, TTG & CG)

	PTG	TTG	CG	p
Age (yrs)	20.36 ± 2.45	20.75 ± 3.17	20.79 ± 3.54	0.426
Weight (kg)	71.26 ± 4.32	72.37 ± 2.24	72.49 ± 3.57	0.230
Height (cm)	171.25 ± 7.16	170.36 ± 3.37	172.12 ± 2.14	0.659

PTG: plyometric trained group, TTG: tabata trained group, CG: active control group

The training intervention lasted for 12 weeks, consisting of three sessions per week. Environmental conditions during the training were controlled to ensure consistency, with sessions conducted in a temperature-regulated indoor facility to minimize external variables affecting performance. Prior to commencing the training, participants were familiarized with the training procedures and outcome measures to ensure comfort and compliance throughout the study. Assessments were conducted before and after the training period, focusing on several outcome measures, including vital capacity, resting heart rate, mean arterial blood pressure, breath-holding time, and respiratory rate. To ensure accurate measurements, all tests were administered with a rest period of 2 minutes between each assessment.

Training Intervention

The training intervention procedure for both Plyometric Training Group (PTG) and Tabata Training Group (TTG) was carefully designed to follow a structured format over a 12-week period, incorporating appropriate warm-up and cool-down routines. Each session lasted for 90 minutes and took place three times a week as shown in Table 2. The program was split into three phases: weeks 1-4, 5-8, and 9-12, with incremental increases in intensity and volume to ensure progressive overload while minimizing the risk of injury. Each training session began with a 10-15-minute dynamic warm-up aimed at preparing the athletes for the upcoming high-intensity activities and reducing the risk of injury. The warm-up included general aerobic exercises such as jogging or light running, followed by dynamic stretches targeting major muscle groups, especially those heavily involved in football performance. Movements such as leg swings, lunges with a twist, arm circles, and hip rotations were incorporated. The final part of the warm-up consisted of sport-specific drills like short sprints, lateral shuffles, and agility ladder drills to activate neuromuscular coordination. A well-structured warm-up has been shown to enhance performance and reduce injury risk in high-intensity activities (Fradkin et al., 2010).

For the PTG, the focus was on developing explosive power through high-intensity, low-repetition exercises targeting the lower body and core. The athletes performed exercises such as squat jumps, box jumps, tuck jumps, lateral bounds, and plyometric push-ups. Each session involved 3-5 sets of 8-15 repetitions, with rest intervals of 1.5 to 3 minutes between sets depending on the week. Work intensity was progressively increased from moderate (Rating of Perceived Exertion [RPE] 6-7) in weeks 1-4, to high intensity (RPE 8-9) in weeks 9-12. Plyometric training has been shown to improve muscular power and overall athletic performance in sports requiring explosive movements like football (Markovic & Mikulic, 2010).

The TTG followed a high-intensity interval training (HIIT) approach based on the Tabata protocol, which involves 20 seconds of maximal effort followed by 10 seconds of rest, repeated for 8 rounds per exercise. Exercises included burpees, jump squats, push-ups, high knees, and mountain climbers. As with the PTG, intensity increased across the phases, starting with moderate intensity (RPE 7-8) in weeks 1-4, progressing to very high intensity (RPE 9-10) by weeks 9-12. Rest intervals between exercises ranged from 2-3 minutes, with shorter rest durations in the later weeks. This form of training has been demonstrated to significantly enhance both aerobic and anaerobic capacities in athletes (Tabata, 2019).

After completing the main workout, each session ended with a 10-15 minute cool-down period. The cool-down involved light jogging or walking to gradually bring down the heart rate, followed by static stretching exercises for the hamstrings, quadriceps, calves, hip flexors, and upper body muscles. Stretching at the end of a workout helps in relieving muscle tension, improving flexibility, and aiding in recovery (Smith, 1994).

Outcome Measures

Vital capacity

Vital capacity was assessed using a spirometer, which measures the maximum amount of air a participant can expel from the lungs after a maximum inhalation. Participants were instructed to take a deep breath and exhale into the spirometer as forcefully as possible, following standard guidelines as referenced (Dridi et al., 2021). This test was repeated three times, and the highest value was recorded as the participant's VC.

Resting Heart Rate

Resting heart rate was measured using a digital heart rate monitor (Model No. EW 243, National Company, Japan). Participants were seated comfortably for five minutes, and the device was placed on their wrist to capture the heart rate. The lowest stable reading after the rest period was recorded, ensuring consistency in line with previous studies (Brini et al., 2021).

Mean Arterial Blood Pressure

Mean arterial blood pressure was determined by using the participants' systolic and diastolic blood pressure readings. Blood pressure was measured in a seated position using a standard sphygmomanometer, and the MABP was calculated using the following formula: MABP = Diastolic BP + 1/3(Systolic BP - Diastolic BP), as recommended by Mathews and Fox (Deepa et al., 2009). This provided a more comprehensive measure of the participants' average blood pressure over a single cardiac cycle.

Table 2. Plyometric Training (PTG) and Tabata Training (TTG) with three weekly sessions for football players 12-week training schedule

Training Schedule	Weeks 1-4	Weeks 5-8	Weeks 9-12
Session Frequency	3 times per week	3 times per week	3 times per week
Training Duration	90 minutes per session	90 minutes per session	90 minutes per session
Work (minutes)	30-40 minutes	35-45 minutes	40-50 minutes
Rest (minutes)	1-2 minutes between exercises	1-2 minutes between exercises	1-1.5 minutes between exercises
Plyometric Training (PTG)			
Sets	3 sets	4 sets	4-5 sets
Repetitions	8-10 reps per exercise	10-12 reps per exercise	12-15 reps per exercise
Rest Between Sets	2-3 minutes	2 minutes	1.5-2 minutes
Work Intensity (RPE Scale)	Moderate (6-7)	Moderate to High (7-8)	High (8-9)
Exercises	Squat jumps, Box jumps, Tuck jumps	Lateral jumps, Depth jumps, Plyo push-ups	Broad jumps, Bounding, Split jumps
Tabata Training (TTG)			
Sets	8 sets	8 sets	8 sets
Work Duration (seconds)	20 seconds per set	20 seconds per set	20 seconds per set
Rest Duration (seconds)	10 seconds between sets	10 seconds between sets	10 seconds between sets
Rest Between Sets (minutes)	2-3 minutes	2-3 minutes	1.5-2 minutes
Work Intensity (RPE Scale)	Moderate (7-8)	High (8-9)	Very High (9-10)
Exercises	Burpees, Mountain climbers, High knees	Jump squats, Push-ups, Speed skaters	Sprint intervals, Plank to push-up, Jump lunges

Breath-holding

Breath-holding time was measured using a nose clip and stopwatch to track the time participants could hold their breath after a maximum inhalation. Participants were seated and fitted with a nose clip to prevent air from entering through the nose. They were instructed to take a deep breath, hold it, and signal as soon as they could no longer continue. The stopwatch was used to record the duration, and the procedure was conducted in accordance with Mathew's method (Ghavipanje et al., 2022).

Respiratory Rate

Respiratory rate was monitored using a bio-monitor, which automatically tracks the number of breaths per minute. Participants were seated, and the bio-monitor was attached according to the manufacturer's instructions. The RR was recorded once the participant was relaxed and breathing naturally, following the previous study procedure described by (Govindasamy et al., 2023).

Statistical Analysis

Prior to conducting the main analyses, data were tested for normality using the Shapiro-Wilk test (Shapiro & Wilk, 1965). All variables met the assumptions of normality ($p > 0.05$), allowing for the use of parametric statistical tests. analyzed using repeated measures analysis of variance (ANOVA) to assess the effects of group (PTG, TTG, and Control) and time (pre-training and post-training) on cardiovascular parameters, including vital capacity (VC), resting heart rate (RHR), mean arterial blood pressure (MABP), breath-holding time (BHT), and respiratory rate (RR). The statistical model tested for the main effects of group and time, as well as group × time interactions (Park et al., 2009). Effect sizes were reported as partial eta squared (ηp^2) to quantify the magnitude of group and time effects, as well as interaction effects. Post-hoc analyses using Cohen's d were conducted to examine the magnitude of changes from pre- to post-training within each group (Cohen, 1988).

Results

All male elite football players successfully completed the allocated treatments, with no training or test-related injuries reported. In terms of cardiovascular efficiency, significant main effects of both group and time were observed across multiple parameters, as shown in Table 3. For VC, there was a significant main effect of group ($p = 0.031$, $\eta p^2 = 0.90$) and time ($p < 0.001$, $\eta p^2 = 2.54$). RHR also showed significant main effects for group ($p = 0.024$, $\eta p^2 = 0.74$) and time ($p < 0.001$, $\eta p^2 = 1.34$). BHT presented a significant main effect for group ($p < 0.001$, $\eta p^2 = 2.48$) and time ($p < 0.001$, $\eta p^2 = 4.12$). Similarly, for RR, significant main effects were found for both group ($p < 0.001$, $\eta p^2 = 2.34$) and time ($p < 0.001$, $\eta p^2 = 2.87$). Moreover, significant group-by-time interactions were identified for all variables. VC demonstrated a significant interaction between group and time ($p < 0.001$, $\eta p^2 = 3.21$), as did RHR ($p < 0.001$, $\eta p^2 = 2.37$), BHT ($p < 0.001$, $\eta p^2 = 2.43$), and RR ($p < 0.001$, $\eta p^2 = 2.75$). These results indicate that the interventions led to meaningful improvements in cardiovascular efficiency, with variations across groups over time. In particular, the groups undergoing PTG and TTG showed significantly greater improvements from pre- to post-training in various cardiovascular parameters. For VC, there was an increase of 30.83 % ($d = 1.24$) in the PTG group and 34.61 % ($d = 1.52$) in the TTG group. RHR decreased by 12.36 % ($d = 1.74$) in the PTG group and by 15.18 % ($d = 1.82$) in the TTG group. MABP showed a reduction of 1.68 % ($d = 1.40$) in the PTG group, while the TTG group experienced a slight increase of 0.38 % ($d = 1.36$). BHT increased by 29.86 % ($d = 2.12$) in the PTG group and by 34.42 % ($d = 2.35$) in the TTG

Table 3. Mean (± SD) values of cardiovascular efficiency variables for the 3 groups (PTG, TTG & CG)

Variables	Group	Before Intervention	After Intervention	% change	p (Cohen d)		
					Main effect group	Main effect time	Interaction group x time
VC (mL)	PTG	3152.00 ± 387.12	4124.00 ± 524.16	30.83	0.031 (0.90)	<0.001 (2.54)	<0.001 (3.21)
	TTG	3247.41 ± 501.25	4371.00 ± 479.15	34.61			
	CG	3179.00 ± 264.34	3879.00 ± 157.58	22.01			
RHR (bpm)	PTG	69.30 ± 4.15	60.73 ± 5.46	-12.36	0.024 (0.74)	<0.001 (1.34)	<0.001 (2.37)
	TTG	69.80 ± 7.34	59.20 ± 6.37	-15.18			
	CG	70.13 ± 4.25	64.80 ± 3.83	-7.60			
MABP (mmHg)	PTG	87.75 ± 3.46	86.27 ± 4.52	-1.68	0.674 (0.74)	0.725 (0.82)	0.214 (0.27)
	TTG	87.54 ± 3.52	87.88 ± 1.24	0.38			
	CG	89.42 ± 2.19	88.12 ± 3.37	-1.45			
BHT (s)	PTG	40.31 ± 6.38	52.35 ± 4.73	29.86	<0.001 (2.48)	<0.001 (4.12)	<0.001 (2.43)
	TTG	39.62 ± 2.54	53.26 ± 5.33	34.42			
	CG	40.36 ± 5.16	43.24 ± 9.64	7.13			
RR (numbers)	PTG	35.12 ± 4.57	25.26 ± 5.54	-28.07	<0.001 (2.34)	<0.001 (2.87)	<0.001 (2.75)
	TTG	36.81 ± 7.54	26.38 ± 2.78	-28.33			
	CG	35.36 ± 6.63	30.26 ± 6.68	-14.42			

Data are mean values (± SD), VC: vital capacity, RHR: resting heart rate, MABP: mean arterial blood pressure, BHT: breath holding time, RR: Respiratory Rate, PTG: plyometric trained group, TTG: tabata trained group, CG: active control group

group. Additionally, RR decreased by 28.07 % (d = 1.04) in the PTG group and by 28.33 % (d = 1.10) in the TTG group. These results emphasize the significant positive impact of both PTG and TTG on a range of cardiovascular efficiency metrics in the participants.

Discussion

Soccer is a physically demanding sport requiring athletes to possess technical and tactical skills and superior cardiovascular fitness to sustain high-intensity actions such as sprints, jumps, and rapid directional changes throughout a match (Chaeroni et al., 2024; Ribeiro et al., 2021). Athletes must improve their anaerobic and aerobic capacity through targeted conditioning regimens to meet these demands. While Tabata and HIIT are well-known for improving metabolic efficiency and endurance, plyometric training well-known for developing explosive power is frequently employed to improve cardiovascular fitness. This study aimed to compare the effects of a 12-week plyometric and Tabata training program on cardiovascular efficiency in elite soccer players and to provide insight into which method is more effective for improving key cardiovascular markers such as VC, RHR, and BHT. The findings offer valuable implications for athletic training by highlighting both training approaches' strengths and potential synergies in soccer.

The explosive, power-driven motions that PTG emphasizes, such as jumps and bounds, have improved cardiovascular indicators like VC, RHR, BHT, and RR. These improvements are consistent with previous literature suggesting that plyometric exercises involving rapid, forceful contractions improve muscle strength, endurance, and cardiovascular efficiency (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020). Plyometric movements are vital for soccer players, mainly due to the frequent acceleration, deceleration, and jumps required during matches (Negra et al., 2020; Ramirez-Campillo et al., 2020). The improvements in cardiovascular efficiency reflect how explosive movements can condition both the muscular and cardiovascular systems (Hughes et al., 2018; Nystoriak & Bhatnagar, 2018). On the other hand, Tabata training, a HIIT technique, emphasizes exercises at total effort interspersed with brief rest intervals. It is well known that using this technique can improve both anaerobic and aerobic performance (Tabata, 2019). In this study, Tabata training slightly outperformed plyometric in terms of some indicators like VC, RHR, BHT, and RR, suggesting that it significantly affects cardiovascular performance. Soccer players who endure sporadic bursts of intense exertion followed by quick rest intervals, emulating the dynamics of a football game, are especially well-suited for Tabata training. The increase in vital capacity and improvement in breath-holding time (34.42% in TTG vs. 29.86% in PTG) can be attributed to the demanding nature of Tabata, which forces the body to optimize oxygen usage and strengthen respiratory muscles.

Cardiovascular efficiency is a critical aspect of soccer performance due to the physical demands of the sport (Oliva-Lozano et al., 2023; Zouhal et al., 2020). Soccer players must sustain long periods of moderate-intensity activity and repeatedly execute high-intensity sprints, jumps, and directional changes (Ribeiro et al., 2021; Stanković et al., 2024). Maintaining performance throughout a match requires cardiovascular adaptations such as increased VO2 max, lowered resting heart rate, and improved respiratory capacity (Nystoriak & Bhatnagar, 2018). The study's conclusions about resting heart rate are noteworthy. RHR decreased in both training groups; however, TTG showed a more significant decline (-15.18%) than PTG (-12.36%). Reduced RHR is a sign of better cardiovascular health since it shows how well the heart pumps blood. Soccer players, who must frequently sprint and recover between bouts of activity, require athletes with lower resting heart rates to sustain high-intensity activities for longer periods and

recover more quickly (Hostrup & Bangsbo, 2023). The lower RHR in both groups emphasizes how plyometric and Tabata exercise promote cardiovascular adaptations. The slightly more significant reduction in the TTG group suggests that HIIT methods like Tabata may provide a more intense stimulus for cardiovascular adaptations due to the constant alternation between maximal effort and short rest intervals. Another necessary cardiovascular adaptation observed was in BHT. The increase in BHT by 34.42 % in the TTG group and 29.86 % in the PTG group indicates improved respiratory endurance and capacity. Increased BHT allows soccer players to sustain maximal efforts without succumbing to oxygen debt, which is crucial during the later stages of matches when fatigue sets in. Increased oxygen delivery and utilization and improved overall cardiovascular function are the results of high-intensity training regimens, further supported by these improvements in BHT (Lu et al., 2023).

The study's limited effect of both training modalities on MABP was one intriguing finding. The PTG group experienced a slight reduction (-1.68 %), while the TTG group showed a minor increase (0.38 %). These minimal changes suggest that MABP was not a primary area of adaptation for these young, healthy athletes already in good cardiovascular health before the intervention. The lack of significant change in MABP contrasts with findings from studies involving untrained or less fit populations, where plyometric and HIIT training often lead to more substantial reductions in blood pressure (Milanović et al., 2015). Given the elite status of the participants, their cardiovascular systems were likely already highly conditioned, which may have reduced the potential for further decreases in blood pressure through these training interventions. This outcome may not be unexpected since neither plyometric nor Tabata training directly targets blood pressure reduction.

The study's findings have significant practical implications for designing soccer-specific training programs. Both plyometric and Tabata training significantly improved cardiovascular efficiency, suggesting that either modality could be effectively incorporated into the conditioning routines of elite soccer players. However, the slightly superior results in the Tabata group suggest that HIIT protocols may offer additional cardiovascular benefits, particularly in improving oxygen delivery and utilization (Lu et al., 2023). This underscores the complementary nature of plyometric training. While Tabata may offer superior cardiovascular benefits, plyometric exercises are critical for developing the explosive power required for jumping, sprinting, and changing direction, which are critical elements of soccer performance. The adaptability of a combined approach incorporating plyometric and Tabata training to provide a more well-rounded conditioning program for soccer players is reassuring, targeting both muscular power and cardiovascular efficiency.

Conclusion

The study demonstrates that 12-week plyometric and Tabata training programs can significantly increase the cardiovascular efficiency of professional soccer players. Both training approaches significantly improved VC, RHR, BHT, and RR, indicating their effectiveness in improving anaerobic and aerobic fitness. Although Tabata training had marginally better effects, especially regarding resting heart rate and breath-holding duration, plyometric training which emphasizes explosive movements crucial for soccer performance remains a vital part of sports conditioning. This study emphasizes the importance of incorporating Tabata and plyometric training into soccer players' conditioning regimens for real-world applicability. Coaches and trainers should consider the specific demands of soccer, incorporating plyometric exercises to build explosive power and agility while leveraging the cardiovascular benefits of Tabata to improve players' endurance and recovery capacity. Further research is warranted to explore the long-term effects of combining these training modalities and assess their impact on match performance, injury prevention, and player longevity. Furthermore, future research might examine how these training techniques can be modified for various demographics, such as female athletes, amateur players, or those recovering from injuries, to maximize cardiovascular fitness and overall performance.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Вплив 12-тижневої програми з виконання пліометричних і Табата-тренувань з частотою 3-х щотижневих занять на продуктивність серцево-судинної системи елітних футболістів

Нідхін Мутхратхіпарамбіл Нараянан[1ABCDE], Каямбу Сундар[1ABCDE], Нірмал Майкл Салві[2CDE], Яшпал[3CDE], Дебаджит Кармакар[4CDE], Сохом Саха[4CD], Бекір Ерхан Орхан[5ACD], Фарджана Актер Бобі[6ACDE], Юні Астуті[7ACDE]

[1]Університет Алагаппа

[2]Міжнародний університет Симбіозис

[3]Державний коледж імені Чиранджі Лала Шарми

[4]Національний інститут фізичного виховання імені Лакшмі Бай

[5]Стамбульський університет Айдин

[6]Міжнародний університет Даффоділ

[7]Падангський державний університет

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

Реферат. Стаття: 9 с., 3 табл., 45 джерел.

Мета дослідження. Це дослідження мало на меті вивчити вплив 12-тижневої програми пліометричних тренувань і режиму тренувань за методикою Табата на продуктивність серцево-судинної системи елітних футболістів.

Матеріали та методи. У дослідженні взяли участь 60 гравців чоловічої статі міжвузівського рівня віком 20,79 ± 1,75 років, яких було розподілено за методом рандомізації до групи пліометричних тренувань (ПТГ, n = 20), групи тренувань за методикою Табата (ТТГ, n = 20) або до контрольної групи (КГ, n = 20). Перед початком та після завершення тренувальної програми оцінювали показники серцево-судинної системи, серед яких життєва ємність легень, частота серцевих скорочень у стані спокою, середній артеріальний тиск, час затримки дихання та частота дихання. Учасники як ПТГ, так і ТТГ виконували 3 тренувальні сесії тривалістю 90 хвилин на щотижневій основі.

Результати. Результати дослідження виявили, що в учасників як ПТГ, так і ТТГ спостерігалося значне покращення продуктивності серцево-судинної системи. Показник життєвої ємності легень збільшився на 30,83 % (d = 1,24, p < 0,001) у ПТГ і на 34,61 % (d = 1,52, p < 0,001) у ТТГ. Частота серцевих скорочень у стані спокою зменшилася на 12,36 % (d = 1,74, p < 0,001) у ПТГ і на 15,18 % (d = 1,82, p < 0,001) у ТТГ. Час затримки дихання збільшився на 29,86 % (d = 2,12, p < 0,001) у ПТГ і на 34,42 % (d = 2,35, p < 0,001) у ТТГ. Частота дихання зменшилася на 28,07 % (d = 1,04, p < 0,001) у ПТГ і на 28,33 % (d = 1,10, p < 0,001) у ТТГ. Отримані дані свідчать про суттєвий позитивний вплив застосування обох методів тренувань на продуктивність серцево-судинної системи елітних футболістів.

Висновки. Таким чином, впровадження програми з виконання пліометричних і Табата-тренувань сприяло значному поліпшенню продуктивності серцево-судинної системи у елітних футболістів, що дозволяє вважати зазначені методики важливими стратегіями передсезонної підготовки щодо підвищення показників витривалості, результативності та загальних спортивних здібностей.

Ключові слова: тренування з футболу, фізіологічні параметри, ВІІТ, тренування з виконання стрибків, футболісти.

Information about the authors:

Narayanan, Nidhin Muthrathiparambil: nithinmnarayan@gmail.com; https://orcid.org/0009-0004-6830-282X; College of Physical Education, Alagappa University, College Rd, Alagappa Puram, Karaikudi, Tamil Nadu 630003, India.

Sundar, Kayambu: sundarajankce@gmail.com; https://orcid.org/0009-0008-3043-9555; College of Physical Education, Alagappa University, College Rd, Alagappa Puram, Karaikudi, Tamil Nadu 630003, India.

Salvi, Nirmal Michael: nirmalsalvi@gmail.com; https://orcid.org/0000-0001-9698-9818; Department of Sports, Recreation & Wellness, Symbiosis International (Deemed University), Lavale, Mulshi, Pune, Maharashtra 412115, India.

Yashpal: yashpalknl@gmai.com; https://orcid.org/0009-0005-7381-9054; Department of Physical Education, Pt. Chiranji Lal Sharma Government College, Sector 14, Karnal, Haryana 132001, India.

Karmakar, Debajit: gowthamadnivog@gmail.com; https://orcid.org/0000-0001-9272-0627; Department of Physical Education Pedagogy, Lakshmibai National Institute of Physical Education, Shakti Nagar, Mela Road, Gwalior, 474002, India..

Saha, Sohom: sohomsaha77@gmail.com; https://orcid.org/0009-0006-9438-1554; Department of Sports Psychology, Lakshmibai National Institute of Physical Education, Shakti Nagar, Mela Road, Gwalior, 474002, India.

Orhan, Bekir Erhan: bekirerhanorhan@aydin.edu.tr; https://orcid.org/0000-0002-3149-6630; Faculty of Sports Sciences, Istanbul Aydin University, Halit Aydın Campus No:38, 34295 Küçükçekmece/İstanbul, Turkey.

Boby, Farjana Akter: boby.pess@diu.edu.bd; https://orcid.org/0000-0003-3168-6888; Department of Physical Education and Sports Science, Faculty of Health and Life Science, Daffodil International University, Daffodil Smart City, Birulia, Savar, Dhaka-1216, Bangladesh.

Astuti, Yuni: yuniastuti@fik.unp.ac.id; https://orcid.org/0000-0001-6430-2938; Faculty of Sports Sciences, Universitas Negeri Padang, Jl. Prof. Dr. Hamka No.1, Air Tawar Bar., Kec. Padang Utara, Kota Padang, Sumatera Barat 25173, Indonesia.

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Original Scientific Article

Exploratory Factor Analysis on the Talent Development Environment Questionnaire (TDEQ-5) for Basketball in Indonesia

Kukuh Hardopo Putro[1ABDE], Suharjana[1ABC], Agus Susworo Dwi Marhaendro[1BCD], Fauzi[1ADE], Danang Wicaksono[1BCDE], Subagyo Irianto[1ABD] and Trisnar Adi Prabowo[1ABCDE]

[1]Yogyakarta State University

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

Corresponding Author: Kukuh Hardopo Putro, E-mail: kukuhhardopoputro@uny.ac.id
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Abstract

Objectives. This study aimed to adapt and measure the level of validity and reliability of the Talent Development Environment Questionnaire (TDEQ-5) for basketball in Indonesia.

Materials and methods. A quantitative approach was employed, using the Exploratory Factor Analysis (EFA) method and Cronbach's Alpha test to determine the reliability of the instrument. The sample comprised 420 basketball athletes (212 men, 208 women) from the Developmental Basketball League, distributed across eight provinces, which were divided into nine major cities in Indonesia. The characteristics of the sample (mean ± SD) were as follows: aged 15 to 18 (17.8 ± 7.2 years old), training experience was 4 to 8 years (5.3 ± 8.9 years), and participating in competitions experience twice to four times a year. The analysis of this study is based on each factor: Long-term development (LTD), Alignment of expectations (AOE), Communication (COM), Holistic quality preparation (HQP), and Social network (SN).

Results. The results showed that KMO-MSA was $p > 0.5$, and Bartlett's Test of Sphericity was $p < 0.05$. Furthermore, Anti-image Correlation, Communalities, and Pattern Matrix Test also exhibited $p > 0.5$. The Cronbach's Alpha value was found to be 0.924.

Conclusions. These findings indicate that the TDEQ-5 is a reliable and valid tool for assessing the talent development environment of basketball athletes, especially in Indonesia. However, further development of this instrument is recommended to be adapted to the sports culture in Indonesia and to ensure a more comprehensive and scientific evaluation of talent coaching in basketball.

Keywords: sports talent, talent coaching, athlete coaching, basketball.

Introduction

The talent development of basketball athletes in Indonesia is an important element in improving both national and international achievements. In recent years, Indonesia has seen an increasing interest in basketball, both among young players and the basketball community in general (Indrayana & Hasibuan, 2021 & Rubiyatno et al., 2022). Nevertheless, to be able to compete at a global level, a structured and supportive talent development system is needed. Therefore, it is important to understand and optimize the talent development environment, which involves various aspects such as support from coach competence, quality of service, and also motivation and commitment of athletes (Juita et al., 2024). Based on previous studies, an easy measurement tool has been found and has a fairly high level of reliability, namely the Talent Development Environment Questionnaire (TDEQ-5) (Alfermann et al., 2023).

The Talent Development Environment Questionnaire (TDEQ-5) is a tool that has been proven effective in various countries in measuring the talent development environment. Several studies have also shown that TDEQ-5 has been used on 538 young athletes in China, (Li et al., 2018), analyzing the perceptions of 92 junior-elite U-19 soccer players about the talent development environment in Norway (Gangsø et al., 2021), as well as evaluating the impact of the talent development environment on team cohesion in water polo in South Africa (Madi et al., 2023). The results of those studies highlight that a good and conducive development environment can have a major effect on the career path of

athletes in the future. This instrument is also able to evaluate important dimensions such as social support, training structure, and development opportunities described in a study of 146 student golf athletes in Malaysia (Manaf et al., 2022). However, until now, there has been no study to adapt or validate TDEQ-5 in various types of sports in Indonesia, especially Basketball. Given cultural, social, and language differences, it is important to make adaptations so that this instrument can provide accurate and relevant results for the Indonesian basketball community (Deviandri et al., 2023).

Adapting TDEQ-5 to sports in Indonesia not only serves to accurately measure the talent development environment but also to provide deeper insights to coaches and sports organizations about factors that can be optimized (Thomas et al., 2020). Then, adapting the Talent Development Environment Questionnaire (TDEQ-5) for basketball talent development research in Indonesia is also very important for several reasons. According to the results of the research that has been found, questionnaire adaptation research can ensure cultural relevance that accurately reflects the local context and is well understood by athletes, coaches, and sports organizations (Gledhill & Harwood, 2019, Apollaro et al., 2022, & Henriksen & Stambulova, 2023), especially in Indonesia. By adjusting the language and context, the validity and reliability of the data collected will increase, so it provides more precise insight into the talent development environment in Indonesia. In addition, the results of this study allow researchers to identify the specific strengths and challenges faced by local athletes, so that talent development policies and programs can be structured more effectively (Gesbert et al., 2021). Adapted tools also facilitate better communication between researchers, coaches, and athletes, thus supporting targeted training strategies to improve the competitiveness of Indonesian basketball athletes (Megicks et al., 2022).

Therefore, this study aimed to adapt and measure the validity and reliability of the Talent Development Environment Questionnaire (TDEQ-5) for basketball in Indonesia. The exploratory Factor Analysis (EFA) method was employed because it provided important initial validation to ensure that TDEQ-5 could be measured consistently in the local context, especially in Basketball in Indonesia (Martindale et al., 2010 & Apollaro et al., 2022). Additionally, the researcher also added a reliability test to measure the internal consistency of the TDEQ-5 items within each identified factor. It is expected that the results of this study will significantly contribute to basketball sports coaching in Indonesia, ensuring that talented athletes receive the support they need to achieve their full potential.

Materials and Methods

Study Participants

The research population consisted of high school students who participated in the Developmental Basketball League (DBL) competition held in eight provinces spread across nine major cities in Indonesia. Sample selection was conducted using purposive sampling, where the selected sample was basketball players who qualified for the DBL Final round. Thus, there were 36 high school basketball teams (18 men's teams and 18 women's teams). Data collection was carried out one day before the start of the final basketball match. Based on the collected sample player data, the total number of players as samples was 420 players (212 male players and 208 female players). The sample characteristics (mean ± SD) were age ranging from 15 to 18 years old (17.8 ± 7.2 years), player training level of 4 to 8 years (5.3 ± 8.9 years), and participating experience in competition of 2 to 4 times in a year.

Study Organizations

This study employed a quantitative method, and the Exploratory Factor Analysis (EFA) approach was used to test the level of validity and reliability. The EFA testing method helped to understand the factor structure of instruments that have not been adapted before and to allow the identification of new factors that may arise due to differences in understanding (Yong & Pearce, 2013). For the results of this study to produce a reliable questionnaire tool, the researcher added an unstructured interview method. The purpose of the unstructured interview method was to analyze responses or comments to be evaluated in the research results (Susiono et al., 2024; Wedi et al., 2024).

This study has four stages. The first stage was to analyze the problems that occur in the basketball environment in Indonesia and review some scientific literature. In the first stage, the first problem identified was that many basketball communities in Indonesia arose from school-age children (Adiansyah et al., 2021; Ningsih et al., 2022; Santoso et al., 2022; Yuliandra et al., 2023; Nurhabibah et al., 2023; Sastra, 2023). The second problem was the lack of talent coaching support on basketball, which caused many players in the basketball community to have skills that go unnoticed. The second stage was the preparation of scientific articles and the search for measuring tools. The results of the second stage were the Talent Development Environment Questionnaire (TDEQ-5) as a measuring tool to be studied in this study. After TDEQ-5 was found, it was then translated into Indonesian based on recommendations of Banville et al., (2000). First, two Indonesian researchers who are bilingual experts in sports science and sports psychology translated the questionnaire. Second, after the TDEQ-5 was translated, it was then discussed by the researchers to produce a single version, conceptually with the original questionnaire and easy to understand. Third, the evaluation of questionnaires was conducted by English experts, sports coaching lecturers, as well as some basketball coaches with a minimum License B. The third stage was data collection, which was carried out in August-November 2024. Data collection was carried out in the Developmental Basketball League (DBL) competition. DBL is an inter-school basketball competition held annually in each province in Indonesia (Rahmaniar & Dewi, 2018; Dikky et al., 2020). The DBL competition is an official competition under the Indonesian Basketball Federation (PERBASI). The fourth stage was the preparation of scientific paper reports, reporting the results of this study by publishing scientific papers through journals. This study has been approved with research permit number B/1516/UN34.16/PT.01.04/2024.

Measurement

At the measurement tool stage, this sub-method section continued from the second stage of this study. The Talent

Development Environment Questionnaire (TDEQ-5) was adopted from research by Martindale et al., (2010), and then it was developed further by Li et al., (2015). Thus, TDEQ-5 produced 25 items in 5 factors, namely 1) Long-term development (LTD), 2) Alignment of expectations (AOE), 3) Communication (COM), 4) Holistic quality preparation (HQP), 5) Social network (SN). After the TDEQ-5 was successfully translated into Indonesian, it was then evaluated in a Focus Group Discussion (FGD) involving English language experts, sports coaching lecturers, and several basketball coaches, with a minimum of License B. The results of the evaluation are stated in the table below.

Statistical Analysis

The data analysis in this study utilized Exploratory Factor Analysis (EFA) to assess the validity of the instrument. In the EFA analysis, the analysis stage was divided into five parts, namely: Kaiser Meyer Olkin Measure Of Sampling Adequacy (KMO-MSA), Bartlett's Test of Sphericity, Anti-image Matrices, Communalities test, and Pattern Matrix Test. The significance level used for EFA analysis based on Bartlett's Test of Sphericity is $p < 0.05$, while the other four parts were >0.5 (Yong & Pearce, 2013). Then, reliability testing used Cronbach's Alpha with a significance value of > 0.7 (Amirrudin et al., 2020). The scale used was 1-5;

Table 1. The Translated Talent Development Environment Questionnaire (TDEQ-5) in English-Indonesian

Long-term development (LTD)	
LTD1	My training is specifically designed to help me develop effectively in the long term. Pelatihan saya dirancang khusus untuk membantu saya berkembang secara efektif dalam jangka panjang.
LTD2	My coach emphasizes that what I do in training and competition is far more important than winning. Pelatih saya menekankan bahwa apa yang saya lakukan dalam latihan dan kompetisi jauh lebih penting daripada menang.
LTD3	I spend most of my time developing skills and attributes that my coach tells me I will need if I am to compete successfully at the top/professional level. Saya menghabiskan sebagian besar waktu saya untuk mengembangkan keterampilan dan kualitas yang menurut pelatih saya akan saya perlukan jika saya ingin bersaing dengan sukses di tingkat atas/profesional.
LTD4	My coach allows me to learn through making my own mistakes. Pelatih saya memperbolehkan saya belajar dengan membuat kesalahan sendiri.
LTD5	I would be given good opportunities even if I experienced a dip in performance. Saya akan diberi kesempatan bagus meskipun saya mengalami penurunan performa.
Alignment of expectations (AOE)	
AOE1	My coach takes time to talk to my parents about me and what I am trying to achieve. Pelatih saya meluangkan waktu untuk berbicara kepada orang tua saya tentang saya dan apa yang ingin saya capai.
AOE2	The advice my parents give me fits well with the advice I get from my coaches. Saran yang diberikan orang tua saya sesuai dengan saran yang saya dapatkan dari pelatih saya.
AOE3	My progress and personal performance is reviewed regularly on an individual basis. Kemajuan dan performa saya secara berkala ditinjau secara individual.
AOE4	I am involved in most decisions about my sport development. Saya terlibat dalam sebagian besar keputusan tentang pengembangan olahraga saya.
AOE5	I regularly set goals with my coach that are specific to my individual development. Saya secara teratur menetapkan tujuan dengan pelatih saya yang khusus untuk pengembangan individu saya.
Communication (COM)	
COM1	My coach and I regularly talk about things I need to do to progress to the top level in my sport (e.g., training ethos, competition performances, physically, mentally, technically, tactically). Pelatih saya dan saya, secara teratur berbicara tentang hal-hal yang perlu saya lakukan untuk maju ke tingkat teratas dalam olahraga saya (misalnya, etos pelatihan, performa kompetisi, fisik, mental, teknik, taktik).
COM2	My coach and I talk about what current and/or past world-class performers did to be successful. Pelatih saya dan saya, berbicara tentang apa saja yang dilakukan para pemain kelas dunia saat ini dan/atau di masa lalu mereka untuk meraih kesuksesan.
COM3	My coach and I often try to identify what my next big test will be before it happens. Pelatih saya dan saya, kerap kali mencoba mengidentifikasi apa ujian besar saya berikutnya sebelum hal itu terjadi.
COM4	My coach explains how my training and competition program work together to help me develop. Pelatih saya, menjelaskan bagaimana program pelatihan dan kompetisi saya bekerja sama untuk membantu saya berkembang.

Table 1 (continued)

Holistic quality preparation (HQP)	
HQP1	My coach rarely talks to me about my well-being. Pelatih saya jarang berbicara kepada saya tentang kesejahteraan/kondisi saya.
HQP2	My coach doesn't appear to be that interested in my life outside of sport. Pelatih saya tampaknya tidak begitu tertarik dengan kehidupan saya di luar olahraga.
HQP3	My coach rarely takes the time to talk to other coaches who work with me. Pelatih saya jarang meluangkan waktu untuk berbicara dengan pelatih lain yang juga melatih saya.
HQP4	I don't get much help to develop my mental toughness in sport effectively. Saya jarang sekali mendapat dukungan untuk mengembangkan mentalitas saya dalam olahraga secara efektif.
HQP5	I am rarely encouraged to plan for how I would deal with things that might go wrong. Saya jarang didorong untuk merencanakan bagaimana menghadapi situasi yang mungkin tidak berjalan sesuai rencana.
HQP6	The guidelines in my sport regarding what I need to do to progress are not very clear. Pedoman yang mengatur langkah-langkah untuk berkembang dalam olahraga saya kurang brgitu jelas.
HQP7	I am not taught that much about how to balance training, competing, and recovery. Saya tidak banyak diajarkan tentang bagaimana cara menyeimbangkan latihan, kompetisi, dan pemulihan.
Social network (SN)	
SN1	Currently, I have access to a variety of different types of professionals to help my sports development (e.g., physiotherapist, sport psychologist, strength trainer, nutritionist, lifestyle advisor). Saat ini, saya memiliki akses ke berbagai jenis profesional untuk membantu pengembangan olahraga saya (seperti fisioterapis, psikolog olahraga, pelatih fisik, ahli gizi, dan konsultan gaya hidup).
SN2	I can pop in to see my coach or other support staff whenever I need to (e.g., physiotherapist, psychologist, strength trainer, nutritionist, lifestyle advisor). Saya dapat berkonsultasi dengan pelatih atau staf pendukung lainnya (seperti fisioterapis, psikolog olahraga, pelatih fisik, ahli gizi, dan konsultan gaya hidup) kapan saja.
SN3	My coaches talk regularly to the other people who support me in my sport about what I am trying to achieve (e.g., physiotherapist, sport psychologist, nutritionist, strength and conditioning coach, lifestyle advisor). Pelatih saya secara rutin berkomunikasi dengan para profesional yang mendukung saya (seperti fisioterapis, psikolog olahraga, ahli gizi, pelatih kekuatan dan kondisi, dan konsultan gaya hidup) mengenai tujuan-tujuan yang ingin saya capai.
SN4	Those who help me in my sport seem to be on the same wavelength as each other when it comes to what is best for me (e.g., coaches, physiotherapists, sport psychologists, strength trainers, nutritionists, lifestyle advisors). Para profesional yang membantu saya dalam olahraga tampaknya memiliki kesamaan visi tentang apa yang terbaik bagi saya (seperti fisioterapis, psikolog olahraga, pelatih fisik, ahli gizi, dan konsultan gaya hidup).

1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), and 5 (strongly agree). The testing of Exploratory Factor Analysis (EFA) and Cronbach's Alpha used SPSS 26.

Results

The following are the results of the validity test in the first stage after data analysis using Exploratory Factor Analysis (EFA). The first stage of EFA analysis is by analyzing the value of the Kaiser Meyer Olkin Measure Of Sampling Adequacy (KMO-MSA) in Table 2.

Based on the results of Table 2, the value of the Kaiser Meyer Olkin Measure Of Sampling Adequacy (KMO-MSA) shows 0.852. This KMO-MSA value is greater than $p > 0.50$, then the significance value of Bartlett's Test of Sphericity is $p < 0.05$, so the analysis can be continued.

After the KMO-MSA is known to be 0.852, the next analysis is by looking at the value criteria in the Anti-image Matrices in Table 3.

Table 2. KMO-MSA Results

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.852
Bartlett's Test of Sphericity	Approx. Chi-Square	1828.096
	df	10
	Sig.	0.000

Based on the results in Table 3, the focus is on the Anti-image Correlation values, denoted by 'a'. The values for factors LTD, AOE, COM, HQP, and SN are 0.857, 0.864, 0.943, 0.811, and 0.813, respectively. All of these values are greater than $p > 0.50$. Therefore, these five factors meet the criteria for Measures of Sampling Adequacy (MSA) as indicated by the Anti-image Correlation values.

The next step involves analyzing the Communalities test values, based on the values in the Extraction section. The results of the Communalities test are shown in Table 4 below.

Table 3. Anti-image Matrices Results

		LTD	AOE	COM	HQP	SN
Anti-image Covariance	LTD	0.273	-0.138	-0.057	-0.065	0.009
	AOE	-0.138	0.267	-0.081	-0.012	-0.043
	COM	-0.057	-0.081	0.441	-0.016	-0.049
	HQP	-0.065	-0.012	-0.016	0.197	-0.139
	SN	0.009	-0.043	-0.049	-0.139	0.215
Anti-image Correlation	LTD	0.857a	-0.511	-0.163	-0.278	0.038
	AOE	-0.511	0.864a	-0.236	-0.053	-0.178
	COM	-0.163	-0.236	0.943a	-0.054	-0.160
	HQP	-0.278	-0.053	-0.054	0.811a	-0.677
	SN	0.038	-0.178	-0.160	-0.677	0.813[a]

a. Measures of Sampling Adequacy (MSA)

Table 4. Communalities Test Results

Communalities		
Item	**Initial**	**Extraction**
LTD	1.000	0.798
AOE	1.000	0.810
COM	1.000	0.689
HQP	1.000	0.830
SN	1.000	0.809

Based on Table 4, the extraction values for factors LTD, AOE, COM, HQP, and SN are 0.798, 0.810, 0.689, 0.839, and 0.809, respectively. These extraction values are all greater than p>0.50, indicating a strong relationship between the variables and the factors.

Following the Communalities test, the next step is the Pattern Matrix test, which produces the component matrix (Table 5).

Table 5. Component Matrix Results

Item	Component
	1
LTD	.893
AOE	.900
COM	.830
HQP	.911
SN	.900

Based on Table 5, the values for factors LTD, AOE, COM, HQP, and SN are 0.893, 0.900, 0.830, 0.911, and 0.900, respectively. All five factors show values greater than p > 0.50 (sample size = 420), and the pattern from the matrix test also indicates that TDEQ-5 is divided into one component. Therefore, TDEQ-5 is proven to be valid as each test item is closely attached to a single instrument.

After conducting the validity test using Exploratory Factor Analysis (EFA), to ensure that the TDEQ-5 instrument has a high level of reliability, a reliability test was conducted. This reliability test uses Cronbach's Alpha values (Table 6).

Based on the results from Table 6, the Cronbach's Alpha value is 0.924, which is greater than 0.7. Additionally, the five factors, LTD, AOE, COM, HQP, and SN, also show reliability values greater than 0.7. Therefore, the Talent Development Environment Questionnaire (TDEQ-5) demonstrates high reliability.

Table 6. Reliability Test Results

Test	Item	Results
Cronbach's Alpha	All Item	0.924
Cronbach's Alpha if Item Deleted	LTD	0.901
	AOE	0.901
	COM	0.924
	HQP	0.906
	SN	0.898

Discussion

This research demonstrates that the Talent Development Environment Questionnaire (TDEQ-5) is a suitable and valid tool when using the Exploratory Factor Analysis (EFA) method. The analysis of the LTD factor proved valid for basketball in Indonesia, indicating that a supportive environment for long-term development is highly relevant in this context. Based on research in Burundi, an ideal talent development environment includes providing sports facilities for young athletes, prioritizing the development of competencies in all sports personnel, and developing youth training centers (Hatungimana & Oladipo, 2023). Moreover, coaches play a crucial role in talent development, as indicated by several LTD items. Competent and qualified basketball coaches should possess qualities such as motivation competency, game-strategy competency, character building, and technique competency (Juita et al., 2024). Furthermore, research by Wijayanti et al. (2024) suggests that qualified coaches should possess mental skills, coaching style, character building, nutrition knowledge, and coaching science. Therefore, coaches play a primary role in the context of talent development in basketball. Organizing age-group basketball tournaments or inter-school competitions is also a method for developing talent (Kalén et al., 2021), as players will continually strive to explore basketball skills that can then be used to evaluate coaches. The LTD factor

approach ensures that athletes not only achieve short-term peak performance but also develop sustainable careers. This is essential given the need to nurture talent continuously to contribute at the national and international levels.

The analysis of the AOE factor as a valid factor underscores the importance of alignment in vision and expectations among coaches, athletes, and other stakeholders in Indonesian basketball. Alignment among coaches, athletes, and stakeholders is crucial for team sports like football, basketball, volleyball, and handball, as it is necessary to achieve desired results for all parties (Van Meervelt et al., 2023). Alignment also creates consistency, such as the support and advice received by athletes, reducing confusion and improving athlete performance and self-confidence (Latief et al., 2024; Mandan et al., 2024). This alignment ensures that everyone is working towards a common goal, minimizing conflict, and increasing the efficiency of training programs. This coordinated approach is believed to enhance athlete satisfaction and motivation in the long term. Another advantage of good alignment between coaches and athletes is that training programs can be designed more efficiently and measurably, allowing athletes to focus on achieving success without distractions (Yi et al., 2021). Additionally, customizing training programs based on individual needs becomes easier, maximizing the potential of each basketball player.

The analysis of the COM factor emphasizes that clear and effective communication is a key component of the basketball environment in Indonesia. Good and harmonious communication between coaches and athletes, especially at the beginning of an athlete's career, is essential, such as having common and realistic goals, suppressing ego, and avoiding bringing problems into the work environment (Karafil & Ulaş, 2023). Furthermore, the involvement of parents with coaches also plays an important role in aligning perceptions about the future for young athletes (Yabe et al., 2021; Mandan et al., 2024). Good communication allows for the exchange of important information and helps build strong relationships between coaches, athletes, and support teams. This plays a vital role in helping athletes understand instructions, receive feedback, and improve their performance. Moreover, the main benefit of good communication among basketball players is to improve teamwork and make it more solid, such as sharing experiences about specific skills among players (Da Silva et al., 2022; Wibowo et al., 2024). Previous research also explains that good communication can lead to creativity in the game, maintain resilience in athletes, cultivate a cooperative spirit, and reduce anxiety (Callaghan et al., 2018; Higgins, 2022, & Luo, 2023). Thus, good communication will influence the level of success for both athletes and coaches.

The analysis of the valid HQP factor highlights the importance of a comprehensive and quality preparation approach in developing basketball athletes in Indonesia. Holistic preparation ensures that athletes receive training that covers physical, mental, and emotional aspects, which is crucial in the early development of a basketball player's career (Rodríguez-Cayetano et al., 2023). Holistic training in basketball teams includes improving technical skills such as dribbling, shooting, passing, as well as effective game strategy and teamwork (de Almeida et al., 2024). In addition, a holistic approach to team sports training also involves education such as nutrition and recovery methods, ensuring that athletes get the right intake for energy and adequate recovery to prevent injuries (Boumosleh et al., 2021; Esen et al., 2022). Thus, holistically prepared athletes tend to have better endurance, a lower risk of injury, and a higher ability to adapt to various on-court situations. Another advantage of a long-term and systematic holistic preparation method is that athletes gain mental well-being. Athletes feel well-cared for and have a sense of satisfaction as athletes, which will eventually impact their motivation to achieve (Lima et al., 2020; Juita et al., 2024). All of these methods support a longer and more successful career in basketball. This perspective supports the development of athletes who are not only ready in technical skills but also in facing the challenges of competition.

The analysis of the SN factor in the TDEQ-5 shows that social support or social networks play an important role in supporting the development of basketball players in Indonesia. Social support from family, friends, and the community has a positive impact on athletes' motivation and well-being. Family support can be in the form of material support and moral support, such as providing training equipment and always trying to be present at every practice session or competition (Mandan et al., 2024; Imtihansyah et al., 2024). Support from friends or the community can be in the form of encouragement before or after a match, joint training, and easy access, such as borrowing a basketball court for practice (Haggar & Giles, 2022; Simons & Bird, 2023). In addition, coaches who have extensive relationships also influence the talent development environment for basketball players. The manifestation of this relationship is bringing in nutritionists, physical therapists, sports psychologists, weight training instructors, and even helping athletes find schools for their academic future (Peng et al., 2020, Krommidas et al., 2022; Sridana et al., 2024). Thus, strong social support can be a source of important moral and informational support in an athlete's career. Moreover, social networks also function as an integral support system, helping basketball athletes develop their talents more effectively and sustainably (Benito-Colio et al., 2022).

The reliability analysis results also show that all factors in the TDEQ-5 have high Cronbach's alpha values. These results indicate that the instrument is consistent in measuring the talent development environment in Indonesian basketball. High reliability gives confidence that the evaluations produced by the TDEQ-5 instrument can be trusted and used as a basis for improving talent development training strategies in basketball (Thomas et al., 2020). It is crucial to ensure that the development of training programs is based on accurate and reliable data through this measurement tool. In addition, the results of the TDEQ-5 testing also provide an easy and credible solution for evaluating talent development systems in Indonesian basketball. Other research suggests that, in addition to measuring physical skills, techniques, and anthropometry in athletes, talent in athletes should be evaluated scientifically (Susanto et al., 2023; Vianna et al., 2024).

The limitations of this study are that when young basketball players provide statements, there are shortcomings such as assessments of basketball organizations and the quality of services such as schools or clubs. Players also believe that organizations have a strong influence on

basketball development in Indonesia, such as through athlete selection or organizing competitions to form layered local teams according to age categories. In addition, the schools that the players attend also need to be assessed regarding how schools support their basketball players in developing basketball skills to become professional athletes. Future research is expected to develop the Talent Development Environment Questionnaire (TDEQ-5) instrument more deeply following Indonesian sports culture, with more detailed analytical methods.

Conclusion

This study concludes that factors such as Long-term Development (LTD), Alignment of Expectations (AOE), Communication (COM), Holistic Quality Preparation (HQP), and Social Network (SN) are proven to be relevant and play a significant role in supporting the development and growth of basketball athletes, especially in Indonesia. The LTD factor emphasizes the importance of an environment that supports the growth of a sustainable career, while the AOE factor shows that the alignment of expectations between coaches, athletes, and related parties increases the efficiency and motivation of training. The COM factor highlights the role of clear communication in building strong relationships and improving athlete performance, while HQP ensures comprehensive and quality athlete preparation, covering physical, mental, and emotional aspects. Support from social networks (SN) is proven to boost motivation and well-being by providing the necessary moral and material support. The high reliability of the TDEQ-5, with a high Cronbach's Alpha value, indicates that the instrument is consistent and reliable, providing a strong foundation for improving talent development training strategies in Indonesian basketball. However, this study also identifies limitations regarding the assessment of the influence of organizations and the quality of services from schools or clubs. Therefore, further development of this instrument is recommended, adapted to the sports culture in Indonesia, to ensure a more comprehensive and scientific evaluation of talent development in basketball.

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Conflict of Interest

The authors has no conflict of interest.

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Дослідницький факторний аналіз використання опитувальника щодо визначення середовища розвитку обдарованості (TDEQ-5) у баскетболі в Індонезії

Кукух Хардопо Путро[1ABDE], Сухарджана[1ABCD], Агус Сусворо Дві Мархаендро[1BCD], Фаузі[1ADE], Дананг Вікаксоно[1BCDE], Субагіо Ірianто[1ABD], Тріснар Аді Прабово[1ABCDE]

[1]Університет штату Джокьякарта

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

Реферат. Стаття: 10 с., 6 табл., 59 джерел.

Мета дослідження. Метою цього дослідження було адаптувати та оцінити рівень валідності та надійності використання опитувальника щодо визначення середовища розвитку обдарованості (TDEQ-5) у баскетболі в Індонезії.

Матеріали та методи. Для визначення надійності інструменту застосовано кількісний підхід із використанням методу дослідницького факторного аналізу (ДФА) та коефіцієнта альфа Кронбаха. Вибірка складалася із 420 баскетболістів (212 чоловіків, 208 жінок) з Баскетбольної Ліги Розвитку, учасників якої було розподілено за вісьмома провінціями, розділеними на дев'ять великих міст Індонезії. Характеристики вибірки (середнє ± СВ) включали наступні показники: вік від 15 до 18 років (17,8 ± 7,2 року), досвід тренувань — від 4 до 8 років (5,3 ± 8,9 року), досвід участі в змаганнях — від двох до чотирьох разів на рік. Проведений аналіз дослідження ґрунтується на кожному із представлених факторів: Довгостроковий розвиток (ДР), узгодженість очікувань (УО), комунікація (КОМ), холістична якісна підготовка (ХЯП) та соціальна мережа (СМ).

Результати. Результати показали, що критерій адекватності вибірки Кайзера-Мейєра-Олкіна становить $p > 0,5$, а критерій сферичності Бартлетта — $p < 0,05$. Крім того, кореляція антиміджів, спільності та критерій матриці патернів також мали показник $p > 0,5$. Значення коефіцієнта альфа Кронбаха становило 0,924.

Висновки. Отримані дані свідчать про надійність та валідність використання TDEQ-5 щодо оцінки середовища розвитку обдарованості баскетбольних спортсменів, що особливо актуально для Індонезії. Однак рекомендується подальший розвиток зазначеного інструменту з метою його адаптації до спортивної культури Індонезії та забезпечення більш комплексної і наукової оцінки тренерської роботи з талановитими спортсменами у баскетболі.

Ключові слова: спортивний талант, тренерська робота з обдарованими спортсменами, баскетбол.

Information about the authors:

Putro, Kukuh Hardopo: kukuhhardopoputro@uny.ac.id; https://orcid.org/0000-0003-1877-1850; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Suharjana: suharjana_pkr@uny.ac.id; https://orcid.org/0000-0002-5241-2395; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Marhaendro, Agus Susworo Dwi: agus_marhaendro@uny.ac.id; https://orcid.org/0000-0003-3055-5771; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Fauzi: fauzi@uny.ac.id; https://orcid.org/0000-0001-9170-3737; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Wicaksono, Danang: danang_wicaksono@uny.ac.id; https://orcid.org/0000-0001-8439-8324; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Irianto, Subagyo: subagyo_irianto@uny.ac.id; https://orcid.org/0009-0008-2551-2965; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

Prabowo, Trisnar Adi: trisnaradi.2022@student.uny.ac.id; https://orcid.org/0000-0001-6977-0503; Faculty of Sport and Health Sciences, Yogyakarta State University, Jl. Colombo Yogyakarta No.1, Karang Malang, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, Indonesia.

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Implementing the Kids' Athletics Program in the System of Increasing the Level of Physical Performance of Youth

Ján Jakubík[1ABCDE] and Jaroslav Broďáni[1ABCDE]

[1]Constantine the Philosopher University in Nitra

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Corresponding Author: Ján Jakubík, e-mail: jan.jakubik@ukf.sk
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Abstract

Objectives. The objective of this study was to verify the impact of the IAAF project "Kids' Athletics" on the physical performance of pupils in primary education through the design and implementation of an athletics program.

Materials and methods. The present study was conducted using a two-group non-concurrent experiment, in which the experimental group (decimal age 8.64 years) consisted of 50 probands and the control group (decimal age 8.55 years) consisted of 60 probands aged 8-9 years. Additionally, 8 physical abilities tests were used to obtain selected indicators of the level of motor performance and probands' skill. The effectiveness of the 7-month experimental program was evaluated using comparative analysis through non-parametric statistical methods: Wilcoxon and Mann-Whitney U test and substantive significance assessment: Cohen (r). The difference in the progress of both samples was also determined.

Results. From a total of 8 motor tests in the experimental sample, a progress was observed in all 8 cases, of which the following changes were significant in 6 tests: Movement Set with Bar ($z = 3.84$, $p < 0.00$, $r = 0.54$), Static Pull-Up Hold ($z = 3.53$, $p = 0.00$, $r < 0.50$), Sit-Up ($z = 5.29$, $p < 0.00$, $r = 0.75$), 3-Way Ball Rolling ($z = 4.31$, $p < 0.01$, $r = 0.61$), the 4×10m Shuttle Run ($z = 4.20$ m, $p < 0.01$, $r = 0.59$) and the Beep Test ($z = 4.64$, $p < 0.01$, $r = 0.66$). In the case of the control group, there was a progress at the level of statistical significance in the Sit-Up ($z = 2.87$, $p < 0.01$, $r = 0.37$), in the 4×10 m Shuttle Run ($z = 4.94$, $p < 0.01$, $r = 0.64$) and the Beep Test ($z = 2.98$, $p < 0.01$, $r = 0.38$).

Conclusions. It has been proven that the "Kids' Athletics" program, composed of selected disciplines of Kids' Athletics supplemented by athletic movement games, has a significant impact on a wider range of physical abilities in 8- to 9-year-old children compared to the traditional content of the ISCED 1 state education program. Based on the findings of this study, as well as the comparison of other research works devoted to related issues, it is pointed out the feasibility of implementing such an athletic program into the annual timetables of Physical Education and Sports in primary education at this particular age period.

Keywords: Kids' Athletics, physical performance, primary education.

Introduction

Physical education and sport, like all education, is closely related to the life around us. They influence each other and are dependent on each other. The educational process in schools should reflect the needs of society and vice versa, individual educational constructs should be modified based on the awareness gained through empirical knowledge from the surrounding world. Currently, the movement aspect of youth is one of the most important topics penetrating various areas. Experts from sports, education, medicine, psychology, sociology, as well as the lay public are interested in a certain way and devote themselves to this issue. The reason is the well-known negative phenomena, which we find based on motor (overall) testing, medical examinations, evaluation of interpersonal relationships, but also by simple observation of the way of life of young people.

The findings of the World Health Organization (WHO) published in the newsletter of the Ministry of Health of the Slovak Republic from 2020 are alarming, pointing to a high global incidence of obesity. More than 340 million children and adolescents between the ages of 5 and 19 suffer from it in the world. Since the 1970s, this number has almost doubled. In most European countries, the prevalence of overweight and obesity is around 50 % in the adult population and is responsible for the development of up to 80 % of type 2 diabetes cases.

Today, perhaps no one doubts that movement and its' lack is one of the main problems of today's young population, along with unhealthy eating habits. Therefore, it is incomprehensible that in several European schools, pupils of younger school age are only required to have 2 PES lessons, during which pupils can move actively and do not have to sit on chairs. The World Health Organization recommends at least 60 minutes of mild to moderately intense exercise per day for people of this age (WHO, 2024). Since physical and sports education is the only or majority source of exercise for most children, we fear that the recommendation of the World Health Organization remains largely unfulfilled. Bielik, Hamar, Penesová, Babjaková, Antala, Labudová and Kovács (2017) point to serious facts that speak of a sedentary way of using free time among school-age children practically throughout the afternoon, i.e. from the time they arrive from school to the end of the day (Bielik, Hamar, Penesová, Babjaková, Antala, Labudová and Kovács 2017). The overall problem is wide-ranging and interdisciplinary. When solving it, we therefore consider it necessary to combine the knowledge and experience of experts from several fields.

In our work, we focus on the implementation of selected athletic elements in the teaching of secondary education with a traditional (2 lesson) time allowance from primary education. At the same time, the research builds on the results of the intervention we carried out in 2020 on a sample of 2nd grade probands. At that time, the high effectiveness of the experimental stimulus in the form of an athletic program implemented in the increased (3 hours) time allowance of the subject of the PES was found. The main reason why we decided to focus on this issue is the great potential in the combination of knowledge and experience from the field of athletics and the education of PES in primary education. It is necessary to point out the fact that in the current prevailing time allocation of two or three lessons a week, we cannot expect miraculous changes in the level of movement performance, or the health side of pupils. Therefore, we understand the main role of PES in providing such activities that, in addition to the development of basic locomotion, will motivate students to do sports and voluntary movement in their free time. Through the implementation of the athletics program in the form of lesson plans, we are trying to provide teachers of this subject with a way to teach athletics at the first level of elementary school more attractively, more efficiently, and considering the age characteristics of the students. The benefit of athletics lies in the improvement of basic locomotion, as well as the development of many movement abilities and skills (Čillík, Blanárová, Nemec and Kozolková, 2018; Katzenbogner et al., 2018; Doležalová and Lednický, 2012; Kuchen, 1986). Often those skills, which are not at the required level when pupils move to the second level of primary school. Katzenbogner et al. (2018) adds that the development of these movement skills is a fundamental task of athletics for children (Katzenbogner et al., 2018). When compiling the athletics program, we were inspired by the practical handbook of team disciplines of the IAAF Kids' Athletics project by the authors Gozzolli, Simohamed and El-Hebil (2006), which serves as a manual for organizers of athletic team competitions of the youngest to middle age of school age almost all over the world. Another important element that we included in the design of the lessons are movement games focused on athletics. These appropriately supplement and dynamize the lessons and, as experts say, in a relatively short time of their application, they also effectively develop motor skills and contribute to the socialization of pupils. In their selection and organization, we were inspired by authors such as Argaj et al. (2009), in addition to our own experience. Adamčák and Nemec (2014) or Katzenbogner, Killing, Fröhlich, Ulrich and Müller (2018). In addition to the mentioned sources, when implementing the athletics program into the annual time-thematic plan for the subject PES, we relied on documents issued by the State Institute of Pedagogy (ISCED 1, 2015) and the Ministry of Education, Science, Research and Sport of the Slovak Republic (Law on Education and Training, 2008). and publications by experts in the field of didactics of PES (Kampmiller, 2002; Šimonek, 2005), didactics of athletics (Čillík et al., 2009), as well as in the field of sports training and development of movement skills by Friedrich (2007) and a team of experts the concept of long-term sports training (Balyi, et al., 2013).

Material and Methods

Study Participants

The basis of the study is the motor performance of boys and girls divided into experimental (n = 50, decimal age 8.64 years, height 134.7 cm, weight 29.9 kg) and control group (n=60, decimal age 8.55, height 134.8 cm, weight 9.9 kg). Between body height, or weight in the experimental and control groups, we did not notice significant differences (p=n.s.).

Study Organization

We used a longitudinal two-group pedagogical experiment to verify the impact of Kids' Athletics on the motor performance of the probands.

To diagnose the entry and exit level of the probands' movement performance, we chose the test battery compiled by the established commission at the Ministry of Education, Science, Research and Sports from 2016/2017. Since 2018, it has been used for full-scale testing of the movement abilities of students in the first and third year of primary education.

The battery of tests consisted of the: Seated Forward Bend (cm), Movement Set with Bar (s), Static Pull Up Hold (s), Standing Long Jump (cm), Sit-up (n/min), 3-Ball Rolling (s), 4x10 m Shuttle Run (s) and Beep test (n).

Statistical Analysis

We assess the statistical significance of changes and differences with the Wilcoxon and Mann-Whitney tests at the significance levels $p < 0.05$ and $p < 0.01$. Material significance is assessed by Cohen's (1988) "r" coefficient: 0.1 – small, 0.3 – medium, 0.5 – large effect. Empirical data were evaluated in MS Excel and SPSS programs.

Results

As a result of the experimental stimulus containing the means of the "Kids' Athletics" program, there were significant improvements in physical movement performance in

Table 1. Physical performance level

Indicators	Experimental sample (n = 50)				Control sample (n= 60)			
	Input		Output		Input		Output	
	M	SD	M	SD	M	SD	M	SD
Height (cm)	134.57	5.93			134.83	6.05		
Weight (kg)	29.98	6.40			29.93	6.64		
Seated F. Bend (cm)	-4.06	8.02	-3.48	8.59	0.18	9.17	-1.71	10.34
Movement Set (s)	23.44	5.42	20.98	4.31	24.43	5.11	26.10	5.90
S. Pull Up Hold (s)	9.90	6.58	12.55	7.67	10.25	6.89	8.98	7.55
Standing L. Jump	135.24	18.37	138.14	16.91	126.63	19.53	127.03	19.13
Sit-Up (n)	34.18	7.47	39.42	7.99	37.88	6.54	40.53	7.08
3-Ball Rolling (s)	27.70	6.05	23.86	5.77	30.85	8.91	28.71	8.46
4x10 m Run (s)	13.90	0.91	13.41	0.77	13.78	0.94	13.35	0.95
Beep Test (n)	26.62	10.08	31.68	11.33	25.00	9.69	28.23	11.85

Performance in individual disciplines (table 1) is characterized by basic descriptive statistics (N – number, M – average, SD – standard deviation)

Table 2. Statistical significance and effect size of physical performance changes in experimental and control sample

Indicators	Sample					
	Experimental			Control		
	z	p	r	z	p	r
Seated F. Bend (cm)	1.41	0.16	0.20	3.08	0.00	0.40
Movement Set (s)	3.84	0.00	0.54	1.82	0.07	0.23
Static P. Up Hold (s)	3.53	0.00	0.50	2.99	0.00	0.39
Standing L. Jump (cm)	1.65	0.10	0.23	0.02	0.99	0.00
Sit-Up (n)	5.29	0.00	0.75	2.87	0.00	0.37
3-Ball Rolling (s)	4.31	0.00	0.61	0.82	0.41	0.12
4x10 m Run (s)	4.20	0.00	0.59	4.94	0.00	0.64
Beep Test	4.64	0.00	0.66	2.98	0.00	0.38

Notes: Wilcoxon test, p value, Cohen's r

Table 3. Statistical significance and effect size of physical performance differences between experimental and control sample in initial and final testing

Indicators	Experimental <> Control sample					
	Input			Output		
	z	p	r	z	p	r
Seated F. Bend (cm)	2.85	0.00	0.40	1.06	0.29	0.15
Movement Set (s)	1.37	0.17	0.19	5.33	0.00	0.75
Static P. Up Hold (s)	0.47	0.64	0.07	2.66	0.01	0.38
Standing L. Jump (cm)	2.08	0.04	0.29	2.78	0.01	0.39
Sit-Up (n)	2.36	0.02	0.33	0.31	0.76	0.04
3-Ball Rolling (s)	1.47	1.14	0.22	3.43	0.00	0.49
4x10 m Run (s)	0.40	0.69	0.06	0.45	0.65	0.06
Beep Test	0.55	0.58	0.08	1.38	0.17	0.19

Notes: Mann Whitney test, p value, Cohen's r

the experimental sample (tables 1 and 2). Performance improvements were noted in the following tests: Movement Set with Bar ($z = 3.84$, $p < 0.00$, $r = 0.54$), Static Hold Pull Up ($z = 3.53$, $p = 0.00$, $r < 0, 50$), Sit-Up ($z = 5.29$, $p < 0.00$, $r = 0.75$), 3-Ball Rolling ($z = 4.31$, $p < 0.01$, $r = 0.61$), 4×10 m Shuttle Run ($z = 4.20$ m, $p < 0.01$, $r = 0.59$) and Beep Test ($z = 4.64$, $p < 0.01$, $r = 0.66$). The level of Seated Forward Bend and Standing Long Jump remained unchanged ($p > 0.05$, $r < 0.23$).

The control sample completed the stimulus with the traditional teaching content of the state education program. The control stimulus had a positive effect on the improvement in the Sit-Up test ($z = 2.87$, $p < 0.01$, $r = 0.37$), $r = 0.32$), in the 4×10 m Shuttle Run ($z = 4.94$, $p < 0.01$, $r = 0.64$) and the Beep Test ($z = 2.98$, $p < 0.01$, $r = 0.38$). Performance level in Standing Long Jump ($z = 0.02$, $p > 0.05$, $r < 0.00$) and Movement Set with Bar ($z = 1.82$, $p > 0.5$, $r = 0.23$) remained

unchanged. The control stimulus negatively affected the level of Seated Forward Bend ($z = 3008$, $p < 0.01$, $r = 0.40$) and Static Hold Pull Up ($z = 1.82$, $p < 0.01$, $r = 0.39$).

It has been shown that the "Kids' Athletics" program, made up of selected disciplines of Kids' athletics supplemented with athletic movement games, has a significant impact on a wider range of physical abilities in 8- to 9-year-old children compared to the traditional content of the ISCED 1 state education program (table 1, 2 and 3). From the physical abilities, positive performance changes were recorded in coordination skills (Movement Set with Bar and 3-Ball Rolling), strength abilities (Static Hold Pull Up and Sit-Up), coordination speed (4×10m) and endurance (Beep Test). The level of mobility and explosiveness of the lower limbs remained unchanged, which can be a positive indicator given the peculiarities of development at this age.

Discussion

The inclusion of athletic elements in the conditions of school physical education, or in children of younger school age, can be observed in several research works. Some are focused on a smaller number of selected monitored indicators; other studies are more complex. Kremnicky (2009) observed the influence of athletic equipment on the development of gymnastic skills. In this work, with the help of a one-group pedagogical experiment, positive changes in the acquisition of selected gymnastic skills were recorded on a sample of 6-7-year-old boys, while among the tools used were basic athletic elements such as running alphabet, sprints and jumps. In the case of the work of Čillik and Willwéber (2018), a positive influence of Kids´ athletics on individual parameters of body composition was found. Similarly, in the case of the work of Willwéber (2016), where a better performance in the general motor performance of 6–7-year-old pupils engaged in athletics was found than in their peers playing tennis.

A team of experts in a series of research conducted in 2013-2015 under the leadership of Čillik devoted themselves to verifying the impact of Kids´ Athletics on a wider complex of movement skills. Experiments on younger school-age probands revealed a significant impact of "Athletics for children" on general motor performance in children aged 7-9 years. The practical part of these researches was carried out on athletics rings at selected elementary schools. The joint results of the works of the involved authors point to the progress of the level of general physical performance. These were proven using the EUROFIT and UNIFIT test batteries. In most cases, the most significant changes in fitness abilities occurred from a series of experiments. When testing coordination skills, similar to our case, the most significant changes in reaction speed and kinesthetic-differentiation skills were recorded. Compared to the pedagogical experiments that we carried out as part of the PES subject at a selected elementary school in the years 2019-2020 and 2023-2024. The subjects of the research under the leadership of Čillik were pupils attending an interest club with an athletic focus. Based on this, in this case we can assume a higher performance homogeneity within groups than when working with students in compact groups (school classes). When working with students of individual classes, in the practice of the subject of PES, we encounter significantly outlier performances of the probands. For this reason, the choice of activities and such means for experimental stimulation, which can be implemented without substantial modifications by the teachers, is more demanding. Nevertheless, we consider the acquired findings of the mentioned team to be beneficial not only for the comparison of results, but also from a methodological point of view.

More comprehensive studies can be found by Petros, Ploutarhos, Vasilios, Vasiliki, Konstantinos, Stamatia and Christos (2016) or Abhaydev and Bhukar (2021). In their studies, Petros, Ploutarhos, Vasilios, Vasiliki, Konstantinos, Stamatia and Christos (2016) devoted themselves to verifying the influence of "Kids's Athletics" on the level of physical skills, performance in selected athletic disciplines and the degree of motivation to continue competing in athletic disciplines. The research was carried out on a wide sample of probands (n = 215) from Greek primary schools aged 11-12 years. Using the division into experimental and control groups, not only changes in the level of physical performance, but also the motivation of the students was observed. We consider this research to be the most widespread pedagogical experiment in natural conditions focused on the implementation of Kids´ Athletics in the teaching of physical education in schools. Similar to our case, here too the experimental stimulus was implemented in the form of modification of the traditional teaching content and then compared with the usual procedure. Compared to CS, more significant changes were recorded in the ES probands in the physical as well as the emotional side, resp. in the motivation of future continuation in athletic competition. The results of the experiment showed an increase in the average motivation of ES probands in performing athletic activities and in (voluntary) continuation of athletic disciplines in the next period. From a statistical point of view, there were no significant changes, however, compared to CS, where a slight decrease in observed interest was recorded, the initiative of Kids' Athletics is evaluated as more successful. When assessing changes in the level of physical abilities (T1: Seated Forward Bend, T2: 10 × 5 m, T3: Standing Long Jump, T4: 20m Shuttle Run, T5: T-Test) as well as performance in athletic disciplines (50 m Sprint, Long Jump, High Jump, Shot Put, Cricket Ball Throw) higher efficiency was recorded in favor of the experimental stimulus in all cases. In addition to the more attractive nature, the authors attribute the success of the experimental program to a higher degree of motivation of the students as well as the teachers themselves when teaching using elements of Kids' Athletics. We agree with the opinion that it is difficult to evaluate the extent to which the results of such research are influenced by the personality of the teachers, their involvement, personal involvement and affection for the chosen method of teaching athletics. From this point of view, we can consider the involvement of a larger number of schools and thus also teachers in the experiment as a slight disadvantage. On the contrary, we consider the size of the sample as well as the comprehensive approach in verifying the effectiveness of research stimuli to be a big positive.

Abhaydev and Bhukar (2021) conducted a two-group pedagogical experiment in a selected elementary school in India on a sample (n = 40) of probands. It was aimed at verifying the impact of Kids' Athletics on selected physical

abilities and skills. Even in this case, statistically significant changes in favor of the experimental set were recorded during the 12-week period. According to the authors, these occurred in all measured indicators (flexibility, explosive leg strength, speed endurance, agility and speed). We see the advantage of the shorter and more intensive intervention period, which was used in the previous two cases, in the reduction of other influences that can have a disruptive effect due to the long-term nature of the research. In the case of our current research in the school year 2023-2024, the effect of the stimuli is concentrated on a longer period of time. For this reason, we emphasized the setting of equal conditions for all "non-experimental" teaching hours of PES and also thorough statistics when evaluating the results.

Conclusions

The main purpose of the contribution was to point out the possibilities of use and effectiveness of the "Kids' Athletics" project in primary education with the help of implementing a special athletics program for 3rd graders. We investigated the influence of the experimental stimulus on the motor performance of the students using input and output measurements. As a battery of motor tests, we used selected tests from the comprehensive testing of movement prerequisites. As such testing is carried out annually in most schools, the data obtained thus provide information not only about the physical level of the probands of both research groups before and after the introduction of stimuli, but also the possibility of comparing these results in a long-term time perspective, or with other sets of tested pupils. While the experimental stimulus was composed of selected disciplines of Kids' Athletics supplemented with athletic games, the control stimulus was based on the original content based on the state educational plan. In both cases, the initiative was implemented in the traditional (2-hour) time allowance of the PES subject.

When evaluating the effectiveness of the experimental stimulus, we start from a comparison of the results achieved in the physical ability tests. Through mutual comparison, we found performance homogeneity between the sets at the beginning of the experimental period using statistical and substantive assessment. When comparing the output tests, we observe a more significant progress in the performance of the experimental sample. We recorded statistically significant changes in the Seated Forward Bend, Static Pull Up Hold, Sit-Up, 3-Ball Rolling, 4x10 m Shuttle Run and Beep Test. Thus, we note the positive influence of Kids´ Athletics and athletic games on physical performance. Based on the above results, as well as the practical applicability of the individual elements of Kids' Athletics, we consider the inclusion of an athletics program in this age period to be effective and thus recommend the creation of sufficient space in the annual schedules of Physical Education and Sports in primary education.

Conflict of Interest

The authors declare that is no conflict of interest.

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Впровадження програми «Дитяча легка атлетика» в системі підвищення рівня фізичної працездатності юного покоління

Ян Якубік[1ABCDE], Ярослав Бродані[1ABCDE]

[1]Університет Костянтина Філософа в Нітрі

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

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Мета дослідження. Метою цього дослідження було перевірити вплив проекту Міжнародної асоціації легкоатлетичних федерацій (IAAF) «Дитяча легка атлетика» на показники фізичної працездатності учнів початкових класів через розроблення та впровадження програми з легкої атлетики.

Матеріали та методи. Дослідження проведено із застосуванням методу двогрупового непаралельного експерименту, в якому експериментальна група (децимальний вік 8,64 років) складалася з 50 досліджуваних, а контрольна група (децимальний вік 8,55 років) — з 60 досліджуваних учасників віком 8-9 років. Крім того, застосовано 8 тестів для визначення рівня розвитку фізичних здібностей з метою отримання окремих показників рівня рухової активності та навичок досліджуваних осіб. Ефективність 7-місячної експериментальної програми оцінювали за допомогою порівняльного аналізу із застосуванням непараметричних статистичних методів: U-критерій Вілкоксона, Манна-Уітні та оцінка змістовної значущості: коефіцієнт детермінації Коена (r). Також визначено різницю в прогресі обох вибірок.

Результати. Загалом із запропонованих 8 рухових тестів в експериментальній вибірці прогрес спостерігався у всіх 8 випадках, з яких наведені нижче зміни виявилися значущими у виконанні 6 тестів: Комплекс рухових вправ зі штангою ($z = 3,84$, $p < 0,00$, $r = 0,54$), статичне підтягування на перекладині ($z = 3,53$, $p = 0,00$, $r = 0,50$), підйоми корпуса ($z = 5,29$, $p < 0,00$, $r = 0.75$), прокочування гімнастичного м'яча у напрямку трьох сторін ($z = 4,31$, $p < 0,01$, $r = 0,61$), човниковий біг 4×10 м ($z = 4,20$ м, $p < 0,01$, $r = 0,59$) та багатоступеневий фітнес-тест ($z = 4,64$, $p < 0,01$, $r = 0,66$). Що стосується контрольної групи, прогрес спостерігався на рівні статистичної значущості у підйомах корпуса ($z = 2,87$, $p < 0,01$, $r = 0,37$), човниковому бігу 4×10 м ($z = 4,94$, $p < 0,01$, $r = 0,64$) та виконанні багатоступеневого фітнес-тесту ($z = 2,98$, $p < 0,01$, $r = 0,38$).

Висновки. Доведено, що програма «Дитяча легка атлетика», яка складається з окремих дисциплін дитячої легкої атлетики, доповнених спортивними рухливими іграми, має суттєвий вплив на розвиток ширшого спектру фізичних здібностей у дітей 8-9 років порівняно із традиційним змістом державної освітньої програми Міжнародної стандартної класифікації освіти (ISCED 1). На основі результатів цього дослідження, а також порівняльного аналізу інших наукових праць, присвячених суміжній проблематиці, наголошується на доцільності впровадження запропонованої легкоатлетичної програми до річного розкладу занять з фізичної культури і спорту в початковій школі у зазначений віковий період.

Ключові слова: дитяча легка атлетика, фізична працездатність, початкова освіта.

Information about the authors:

Jakubík, Ján: jan.jakubik@ukf.sk; https://orcid.org/0009-0004-5368-3148; Department of Physical Education and Sport, Faculty of Education, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 949 01 Nitra, Slovak Republic.

Broďáni, Jaroslav: jbrodani@ukf.sk; https://orcid.org/0000-0002-0126-8514; Department of Physical Education and Sport, Faculty of Education, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 949 01 Nitra, Slovak Republic.

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Review Article

Identifying the Research Trend of Sport Biomechanics over the Last 20 Years: A Bibliometric Analysis of the Scopus Journal Database

Muchamad Arif Al Ardha[1ABCD], Nurhasan Nurhasan[1ADE], Dwi Cahyo Kartiko[1ADE], Chung Bing Yang[2ADE], Sauqi Sawa Bikalawan[1BCD], Ainun Zulfikar Rizki[1BCD] and Sevesti Violin Wilujeng Herista[1BCD]

[1]Surabaya State University
[2]National Dong Hwa University

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

Corresponding Author: Muchamad Arif Al Ardha, e-mail: muchamadalardha@unesa.ac.id
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Abstract

Background. Sports biomechanics is an important part of coaching and athlete conditioning. The training process can be maximised through the implementation of sports biomechanics. Research related to sports biomechanics has grown significantly in recent years.

Objectives. This systematic review study aimed to analyse the development trend of sports biomechanics research over the last 20 years.

Materials and methods. This study used a bibliometric approach and a systematic review of the SCOPUS journal database to analyse research trends in the field of sports biomechanics.

Results. Over a period of twenty years, there were 259 studies that met the inclusion criteria. The analysis results showed a significant increase in the number of published studies over time, with a total of 2215 citations and an average of 1237 citation. The research tends to focus on biomechanical principles in the context of sports, with the keyword "Biomechanics" being the most dominant. The terms "Sport Biomechanics", "Human", and "Sports" were also identified as frequently occurring keywords in the research. In addition, these studies cover various aspects related to human body movement, including movement analysis, health aspects, and technology applications in sports.

Conclusions. This study provides insight into the major developments and focal aspects in sports biomechanics over the past two decades, as well as highlighting the diversity of research subjects within this field.

Keywords: coaching, sport science, training, athlete conditioning.

Introduction

Sports biomechanics research has developed significantly (Knudson, 2020). This field has played a crucial role in understanding how the human body interacts through movement (Yang, 2013), exercise (Patoz et al., 2023), and sports games (Muñoz et al., 2023). Analysis of research developments in sports biomechanics has brought us more depth regarding movement efficiency (Mishra, Singh, Ranjan, Singh, & Vidyarthi, 2019), injury prevention (Friesen & Oliver, 2022), and increased movement abilities (Tai et al., 2022).

Improving athlete performance can be achieved by understanding the mechanics of movement (Garcia, Guereño, Nuñez, & Etxarri, 2023) and how the body interacts with training loads (D. Zhang & Wang, 2023). Trainers can use biomechanical analysis to design more effective training programs (L. Zhang, 2020). This can help athletes reach their maximum potential in competition (Mujika, Halson, Burke, Balagué, & Farrow, 2018). The results of relevant sports biomechanics studies are very necessary to win at increasingly fierce levels of competition in sports (Barbosa et al., 2021).

Advances in technology used in sports biomechanics, such as high-speed cameras and inertial sensors (R. Howard, 2016), have opened the door to very detailed movement analysis (Hiley, 2012). This is not only relevant in the sports context, but also in medical rehabilitation and general health

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care (Akiyama, Nakashima, & Ogasawara, 2011). Research in sports biomechanics requires the ability to manage and analyze very large and complex data (Pataky et al., 2023). These data analysis skills can determine the effectiveness of the follow-up given to athletes (Haralabidis et al., 2021).

Biomechanics research also provides valuable insight into why injuries occur and how they can be prevented (Jang, Chang, Chen, Fu, & Lu, 2009). It is important to treat sports injuries because injuries are a serious problem that can end an athlete's career and have long-term impacts (Kent, 2019). Identifying injury risk factors and developing safer training techniques is not only important for professional athletes, but also for those involved in amateur sports.

However, the development of sports biomechanics research has not yet been systematically mapped. This bibliometric research and systematic review aim to look at the development of sports biomechanics research trends in the last 20 years with the following research questions:

- To analyze sport biomechanics research trends in the last 20 years.
- To evaluate the most countries contributed sport biomechanics research in the last 20 years.
- To discover the subject areas related to sports biomechanics research in the last 20 years.
- To analyze the keyword trends of sports biomechanics research in the last 20 years.
- To analyze the top 10 cited publications in sports biomechanics research in the last 20 years.

Materials and Methods

This type of research is a Bibliometric Analysis and Systematic Review. Article searches were carried out using a comprehensive strategy on SCOPUS research journal databases. The keyword used during the identification was "sport biomechanics". In addition, the exclusion criteria were journals non-English journals published in the last 20 years from 2023. There were 544 articles from SCOPUS that were mined on October 10th, 2023. Therefore, 259 articles were selected for further analysis by using VOS viewer computer software. There were 10 articles selected as the most cited articles and relevance which were selected for this systematic review. For standard operationalization, this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Figure 1).

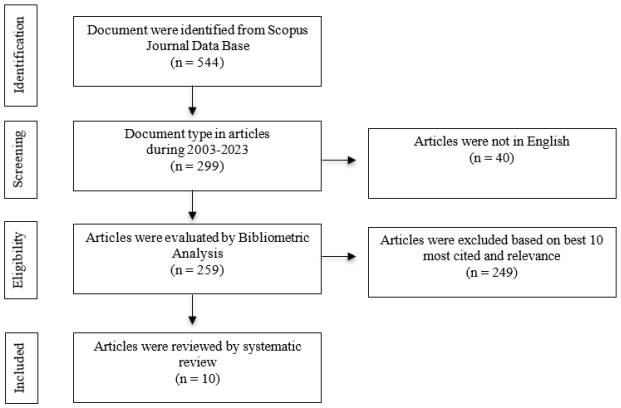

Fig. 1. PRISMA flowchart of the article selection process

Results

Research Trends of Sport Biomechanics in the Past 20 Years

The number of biomechanics articles published (n) has fluctuated over this 20 year period. The trend is not monotonous, with certain years seeing a significant increase in publications. This suggests that research interest and focus in sports biomechanics has evolved and changed over time. However, there has been a significant increase in total citations since 2017, which may reflect increased interest and recognition in sports biomechanics research. Overall, the data in table 1 illustrate significant developments in sport biomechanics over the past two decades.

Table 1. Document of sport biomechanics identified in the last 20 years

Year	n	Total Cited	Average Cited
2003	2	45	23.50
2004	0	0	0.00
2005	3	45	24.00
2006	3	69	36.00
2007	5	277	141.00
2008	2	64	33.00
2009	3	35	19.00
2010	7	174	90.50
2011	4	41	22.50
2012	9	141	75.00
2013	16	171	93.50
2014	8	96	52.00
2015	6	85	45.50
2016	7	76	41.50
2017	25	101	63.00
2018	16	175	95.50
2019	27	183	105.00
2020	20	186	103.00
2021	36	189	112.50
2022	33	54	43.50
2023	27	8	17.50
Total	259	2215	1237.00

Biomechanics research developed rapidly in 2013 (Figure 2). This is evidenced by the lack of research on sports biomechanics before 2013. In early 2003 research focused more on the variables of distance, height, time and speed. In early 2012 biomechanics research developed to involve other variables such as algorithms to see accuracy, sensor technology for measurements, and the use of IT technology. However, since 2021 there has still been no research involving the latest variables. It is possible that the development of sports biomechanics research will be affected by the Covid-19 pandemic phenomenon.

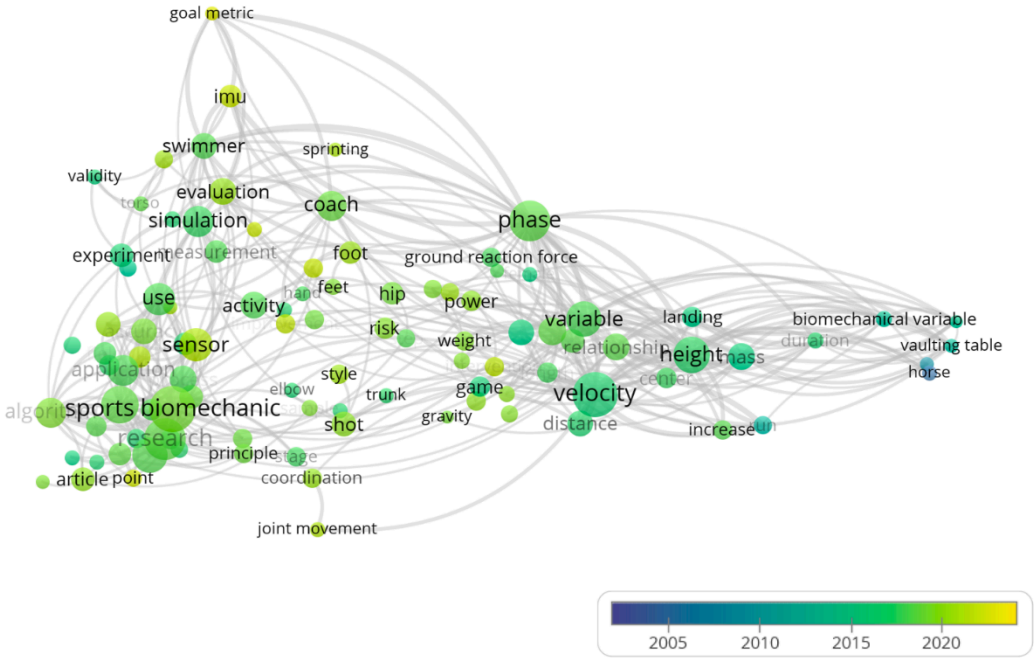

Fig. 2. Research topic trends in sport biomechanics research

Country Contributed to Sport Biomechanics in the Last 20 Years

Researchers selected the top 10 countries as the countries that contributed the most in the field of sports biomechanics (Table 2). Based on these results, one of the countries in Asia, namely China, dominates with contributions made almost twice as much as countries in Europe. However, the most citations are shown by countries in Europe.

Table 2. Top 10 countries contributed to sport biomechanics research

Country	n	Total Cited	Average Cited
China	71	308	189.50
United States	47	680	363.50
United Kingdom	30	444	237.00
Australia	18	215	116.50
Japan	17	107	62.00
Canada	14	229	121.50
Italy	13	199	106.00
Indonesia	10	20	15.00
Taiwan	8	19	13.50
Switzerland	8	36	22.00
Total	236	2257	1246.50

Overall, countries contributing to biomechanics research are in figure 3. The United States leads in total citations, while China has the most articles. Almost all continents contribute to biomechanics research except Africa. However, various collaborations between countries also occur in sports biomechanics research. The rapid development of biomechanics from various countries reflects the urgency of sports biomechanics in improving athlete performance.

Subject Areas Related to Sport Biomechanics in the Last 20 Years

In the field of Biochemistry, Genetic, and Molecular Biology, it was ranked 4th and contributed 66 articles with a total of 576 citations (Table 3). This illustrates the relevance of research at the cellular and molecular level in the context of sports biomechanics. Fields related to medicine and biomechanics collaborate to maintain the health and physical fitness of individuals, prevent injuries, understand the technical aspects of sports, and develop more effective medical devices. Collaboration between these two fields is key to providing better care to athletes, patients and the general public. It also reflects the importance of physical health and sports injuries in the context of biomechanics.

Table 3. Top 10 subject areas contributed to sport biomechanics research

Subject Areas	n	Total Cited	Average Cited
Medicine	114 (20.99 %)	1386	750.00
Engineering	106 (19.52 %)	853	479.50
Health Professions	81 (14.92 %)	811	446.00
Biochemistry, Genetics, and Molecular Biology	66 (12.15 %)	576	321.00
Computer Science	45 (8.29 %)	172	108.50
Social Science	42 (7.73 %)		42.00
Physics and Astronomy	28 (5.16 %)	107	67.50
Materials Science	24 (4.42 %)	62	43.00
Chemical Engineering	24 (4.42 %)	112	68.00
Agricultural and Biological Sciences	13 (2.39 %)	104	58.50
Total	543 (100 %)	4183	2363.00

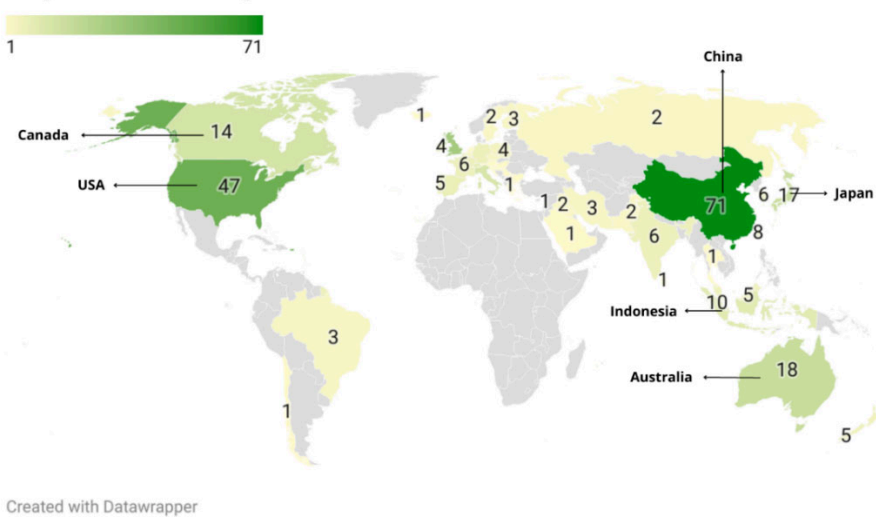

Fig. 3. Countries contributed to sport biomechanics research

The field of Engineering has a significant contribution to sports biomechanics research. Engineering has 106 articles contributing to sports biomechanics research. With a total of 853 citations and an average of 479.50 citations. Biomechanical engineering and technical approaches have played an important role in understanding human movement in the context of sport. Followed by Health Professions, which reflects the close relationship between biomechanics research and aspects of physical health, especially in treating and preventing sports injuries.

Computer Science has 45 articles contributing to sports biomechanics. The fairly high average citation (108.50) reflects the use of computer technology and modeling in research. The field of Computer Science also provides sophisticated data modeling and analysis. With a high average citation, this reflects technological developments in supporting biomechanics research. In this series, other fields such as Materials Science, Physics, and Social Sciences also have a role in understanding human movement and sports. Overall, this table reflects the diversity and complexity of research in sport biomechanics as well as the interconnections between various scientific fields that support a holistic understanding of human movement and sport.

Keyword Pattern in Sport Biomechanics Research Trend

The keyword "Biomechanics" dominates this list with a total of 121 studies (19.39 %). This reflects that a basic understanding of biomechanics is the main foundation in research in the field of sports biomechanics (Table 4). Biomechanics is a science that allows researchers to analyze human body movements scientifically. Using the principles of physics, mathematics and engineering, this research covers various aspects related to human movement, from the

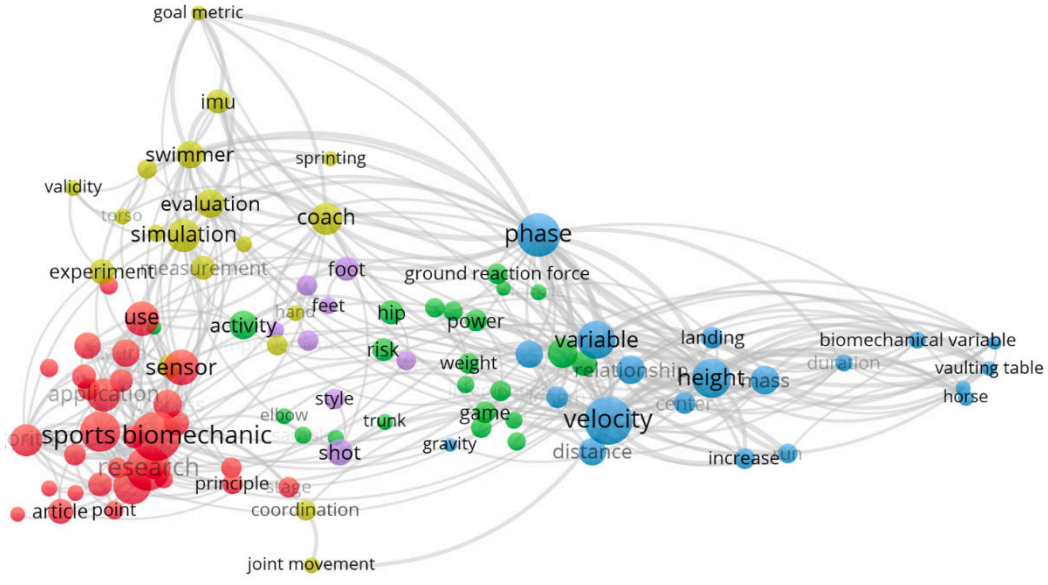

Fig. 4. Keyword interaction in sport biomechanics research

analysis of sports movements to the development of more efficient sports equipment. With a total of 1475 citations and an average of 798 citations, the term "Biomechanics" consistently appears in the scientific literature and has had a major impact on the development of this science.

Biomechanics research includes aspects such as human movement mechanisms, the human body's response to physical exercise, and the influence of physical factors on sports performance mapped by looking at connections in keywords (Figure 4). In general, there are 5 main keywords that are most dominant in relation to other keywords and form clusters. In cluster 1 (red), the sports biomechanics keyword is closely related to velocity (cluster 2/blue) and simulation (cluster 3/yellow). This proves that there is collaboration between various keywords to dig up deeper information on biomechanics.

Top 10 Cited Publications of Sport Biomechanics Research in the Last 20 Years

Table 4. Top 10 keyword patterns for sport biomechanics research

Keyword	n	Total Cited	Average Cited
Biomechanics	121 (19.39 %)	1475	798
Sport Biomechanics	97 (15.54 %)	1020	558.5
Human	93 (14.90 %)	1417	755
Sports	79 (12.66 %)	645	362
Biomechanical Phenomena	50 (8.01 %)	606	328
Kinematics	46 (7.37 %)	701	373.5
Sports Medicine	44 (7.05 %)	333	188.5
Physiology	37 (5.93 %)	749	393
Biophysics	29 (4.65 %)	334	181.5
Movement	28 (4.49 %)	208	168
Total	624 (100 %)	7588	4106

Table 5. Sports biomechanics top 10 cited publications in the last 20 years

Author	Total Cited	Research Purposes	Methods	Results
Aguinaldo, Buttermore, & Chambers, 2007	193	To analyse how torso rotation affects shoulder rotational torque during pitching.	Comparative	It suggests that certain throwing patterns can improve fielding efficiency, allowing players to perform better while reducing the risk of injury.
Glazier, 2010	125	To discuss key issues in the emerging sports science subdiscipline of performance analysis and future prospects.	Constraints-based approach	Performance analysis may be more suitable for sports biomechanics analysts and notation analysts than for sports scientists from other sports subdisciplines, such as sports physiology and sports psychology.
Song, 2013	84	To examine the rationality of the Fosbury flop method and current technology, as well as to provide reasonable recommendations for building a theoretical and sporting foundation.	Study on the analysis and simulation	This paper makes a reasonable analysis of the fosbury flop and perfect movement reduction using the principles of sports biomechanics.
Mihalik et al., 2012	69	To determine whether playing position, match type, or head impact location had an effect on head impact biomechanics measured in Bantam (13 and 14 years old) and Midget (15 and 16 years old) ice hockey players.	Prospective quantitative research	Impacts to the side of the head result in much higher rotational acceleration than impacts to the top, front, or back. Impacts to the head are more severe during matches than during training.
Taborri et al., 2020	56	To provide an overview of sports biomechanics applications found in recent literature that utilize wearable sensors. The research shows some information related to the sensors used as well as methods to analyze the data.	Literature review	To assess athlete performance, inertial sensors seem to be the most widely used. However, force sensors and electromyography are also used.
Wilson, 2008	56	To improve athlete and coach performance through increasing their understanding of every aspect of athlete performance.	Mix methods	Development areas that will enhance the use of video in training include real-time skill analysis, real-time automatic coding, and smart systems for motion analysis.
N. Li et al., 2018	52	To reduce stroke complications and assist body movement, a soft bionic ergonomic exoskeleton robot with 7 DOF was proposed.	Research and Development	The robot can help dyskinesia stroke patients restore their joint motion function and help them complete leisure activities (ADLs) such as drinking, eating, etc.

Table 5 (continued)

Author	Total Cited	Research Purposes	Methods	Results
Harpham, Mihalik, Littleton, Frank, & Guskiewicz, 2014	52	To determine how sensory and visual performance correlates with the severity of head impacts of football players and how visual and traditional sensory reaction time measurements are measured.	Prospective quantitative research	We found a significant relationship between head impact severity and visual and sensory performance; lower visual and sensory performance was associated with more severe head impacts.
Pappas, Sheikhzadeh, Hagins, & Nordin, 2007	52	To find out how gender and fatigue affect the peak values of biomechanical variables during landing from a jump.	Experimental study	Landing with a vertical ground reaction force and higher peak knee valgus may lead to a higher risk of knee injury in women.
Choppin & Wheat, 2013	46	To investigate the accuracy of Kinect in three domains: body scanning and anthropometry, segment tracking for motion analysis, and image segmentation for training and notation analysis.	Comparative	Kinect is currently not accurate for research that requires high accuracy and precision.

Biomechanics Optimizing Athletic Performance and Injury Prevention

Sports biomechanics has experienced significant progress as a science that combines the principles of physics with a deep understanding of human body movement. Through careful analysis, biomechanics helps athletes achieve their peak performance while minimizing the risk of injury. Aguinaldo et al. (2007) analyzed how torso rotation affects shoulder rotational torque during pitching in baseball and showed that understanding biomechanics can identify efficient throwing patterns. This not only increases efficiency on the field, but also allows players to perform better with a lower risk of injury. These findings make an important contribution for coaches and players to develop safer and more effective techniques in their sport. Furthermore, Glazier (2010) discusses key issues in the newly emerging subdiscipline of sports science, namely performance analysis. The constraints-based approach used in his research offers a new perspective in biomechanical analysis and may be more suitable for sports biomechanics analysts than for sports scientists from other subdisciplines. This emphasizes the importance of biomechanics not only as a tool to improve performance but also as a field of study that continues to develop and adapt to the needs of athletes and coaches.

Mihalik et al. (2012) revealed that impacts on the side of the head cause much higher rotational acceleration than impacts on the top, front, or back of the head. In the context of the sport of ice hockey, this understanding is crucial because it provides insight into how playing position, type of match, and location of head impact influence the impact biomechanics experienced by players, and this can be used to develop better protective equipment. Similarly, Taborri et al. (2020) indicate that inertial sensors appear to be most widely used to assess athlete performance. This research provides an overview of how sports biomechanics applications using wearable sensors can be applied in training and rehabilitation practices to monitor and improve athlete performance and reduce the risk of injury. Through the continued analysis and development of studies such as these, sports biomechanics continues to make valuable contributions to the world of sport. The integration of biomechanics in sports has been and will continue to be a critical pillar in efforts to optimize athletic performance and prevent injury.

The Development Biomechanics Methodology in Sports Science

Biomechanics has transformed and developed from simply the study of movement mechanics to become a critical foundation in sports science. Through the evolution of methodologies and interdisciplinary approaches, sports biomechanics now allows a more complex and holistic analysis of athlete performance. In a broader context, new methodologies in sports biomechanics involve the use of advanced technologies, such as computer modeling and movement simulation, as illustrated by Song's (2013) research on the Fosbury flop technique. The research uses biomechanical principles to analyze and refine technique in the high jump, showing how the theory and application of biomechanics can collaborate to produce recommendations that can form the theoretical foundation and practice of the sport. Advances in measurement technology and data analysis have also enabled researchers such as Mihalik et al. (2012) to study the impact of biomechanics from different angles. In their study of ice hockey players, they found that playing position, match type, and impact location on the head significantly influenced the measured impact biomechanics. This shows the importance of a specific and measurable approach in understanding and applying biomechanical concepts.

Finally, recent developments in biomechanical methodology include the integration of wearable sensors in sports research and training, as outlined by Taborri et al. (2020). This research offers an overview of sports biomechanics applications found in recent literature, showing how wearable sensors are used to collect athlete performance data. Through the integration of new scientific disciplines, technologies and methodologies, sports biomechanics continues to evolve and contribute to increased understanding of athlete performance. This discussion can be developed further by adding specific data and examples from the tables provided to support each point and illustrate how scientific discoveries have been applied in sports practice.

The Technological Innovation in Sports Biomechanics

Technological innovations in the field of sports biomechanics have brought about significant changes in the analysis and understanding of athletic movements. Advanced tools such as movement monitoring systems and computer simulations have enabled researchers to measure and analyze movement with extremely high precision, providing new insights into performance optimization and injury prevention strategies. For example, research by Aguinaldo et al. (2007) who examined the effect of torso rotation on shoulder rotational torque in pitching found that "certain throwing patterns can improve fielding efficiency, allowing players to perform better while reducing the risk of injury" (Aguinaldo et al., 2007). These findings not only enrich our knowledge of pitching biomechanics but also aid in the development of training techniques that can optimize performance and improve athlete safety. Mihalik et al. (2012) showed that "impacts to the side of the head produce significantly higher rotational accelerations than impacts to the top, front, or back of the head. Impacts to the head are more severe during competition than during training" (Mihalik et al., 2012). These findings are important in understanding the biomechanics of head impacts and can be utilized to design more effective protective equipment. Advances in wearable technology have also played an important role in sports biomechanics. As stated by Taborri et al. (2020), "inertial sensors appear to be the most widely used to assess athlete performance, but force sensors and electromyography are also used" (Taborri et al., 2020). This information emphasizes the importance of wearable technology in collecting accurate and real-time data that can be directly applied in athlete training.

Thus, technology has opened new avenues in sports biomechanics, not only in research but also in practical applications. Tools such as real-time video analysis systems, automatic coding, and smart systems for movement analysis, as described by Wilson (2008), "develop areas that will increase the use of video in training including real-time skill analysis, real-time automatic coding -time, and intelligent systems for movement analysis" (Wilson, 2008). The integration of this technology in athlete training and rehabilitation helps ensure that athletes can reach their full potential while maintaining their health and safety.

Discussion

Over the past two decades, sports biomechanics has seen an impressive evolution and diversification. This study was conducted with the aim of analyzing the development of research trends in sports biomechanics in the last 20 years. The research trend shown based on the results of the analysis is a significant increase dynamically from year to year. The development trend of sport biomechanics research began to be shown in 2005. From 2005-2010, the focus of sport biomechanics research was to discuss the principles or role of biomechanics in general. Research related to the scope of sports is still rare.

In 2011-2023, sport biomechanics research developed fluctuatively and dynamically. In these years, research related to all aspects of sport began to be conducted frequently, especially related to the scope of health. The contribution of sport biomechanics research in the scope of health is 20.99% of the total number of publications identified in this study. The role played by several countries in sport biomechanics research represents the intensity and interest in sport biomechanics research. China dominates with almost twice the contribution of European countries. The number of publications shown is 71 publications, this shows that China is very enthusiastic in developing sport biomechanics in its country.

Based on the results of the literature review, sport biomechanics research in the early 21st century was only able to measure in two dimensions. Currently, sport biomechanics research is able to measure in three dimensions, and provide data in real time. This development can occur due to the development of technology as well. The era of digitalization provides benefits with the creation of wearable devices that are able to measure and analyze the motion of a person in real time. The role of technology and computational tools in this growth cannot be overstated. With the adoption of sophisticated equipment like motion capture systems, force plates, and advanced simulations, researchers have been able to dissect athletic movement with unparalleled detail. This technological leap has allowed for more nuanced biomechanical questions to be asked and answered, offering tangible benefits for enhancing sports performance. The performance improvement that occurs in an athlete is related to the effectiveness of the movements performed. When the resulting motion is appropriate and effective, the risk of injury will decrease or even be able to avoid sports injuries.

Sports biomechanics research in the last two decades has experienced rapid progress, especially thanks to the development of increasingly sophisticated technology and movement evaluation devices (Howard et al., 2016). This has allowed researchers to observe and analyze human body movements with a high level of detail and accuracy (Amerineni et al., 2021). As a result, we now have a better understanding of the biomechanics of various sports, starting with running (Buxadé et al., 2021), swim (Izumi, Hyodo, Yoshioka, & Wada, 2023), a small ball game (Milanovich & Nesbit, 2014), big ball game (Slegers, Lee, & Wong, 2021) to heavy sports such as weightlifting (Sorensen, Haddad, Campbell, & Mirka, 2011).

One of the significant impacts of this research is the ability to optimize athlete performance (Waters, Phillips, Panchuk, & Dawson, 2019). With a better understanding of movement mechanics, trainers can design more effective training programs (L. Li, 2012). Biomechanical analysis also helps in preventing sports injuries by identifying potential excess stress on an athlete's body (Yan et al., 2023). This way, athletes can train smarter and safer (Ma & Huo, 2022). Not only in the world of competitive sports, but sports biomechanics research also has important implications in injury recovery (Zhu, Zhang, Sun, & Qi, 2021). A better understanding of body mechanics helps medical professionals design more effective rehabilitation programs (C. Zhang, Chen, Cao, Zhang, & Chen, 2019). This has helped many athletes overcome their injuries and return to their best performance (Wei & Yalong, 2021). Over the past two decades, there have also been developments in in-depth data analysis (Warmenhoven et al., 2019). Increasingly sophisticated statistical and computational methods allow researchers to analyze biomechanical data with greater precision (Knowles

& Dennison, 2017). This opens the door to more in-depth and accurate findings about how the human body moves in various sporting situations (Amarantini, Amarantini, Martin, Cahouët, & Berton, 2012).

Additionally, developments in communication and knowledge sharing have enabled sport biomechanics researchers to collaborate more effectively (Umek & Kos, 2016). They can share their discoveries with the wider scientific community (Xiang et al., 2022), accelerating the process of discovery and implementation of these findings in the world of sports (Amarantini, Rao, & Berton, 2010). However, challenges have also remained in recent years (Glazier & Mehdizadeh, 2019). Ethical debates arise with the use of monitoring technology in sports (Murray & Chuan, 2017). Questions about privacy, data use, and the influence of technology in sports competitions have become increasingly relevant topics (Luo, 2021). With all these developments and challenges, sports biomechanics remains an interesting and important field in the world of sports (Bartlett & Bussey, 2013). Research in this area continues to make valuable contributions to improving athlete performance, preventing injury, and deeper understanding of the human potential in sport (Forte, Neiva, & Marinho, 2021). The future of sports biomechanics research promises many more innovative findings that will help shape the world of sports in the future (Gutierrez, Walton, & Bezodis, 2023), (Yan-Xia, Lin, & Chong-Long, 2019), (King & Yeadon, 2015).

Conclusions

Sports biomechanics has witnessed remarkable growth and diversification in the last 20 years, as evidenced by our comprehensive bibliographic analysis and systematic review of the Scopus Journal Database. This study explored the key research trends, publication patterns, and the evolving focus of sport biomechanics research during this time frame. Sports biomechanics research has transcended geographical boundaries, with contributions from researchers and institutions worldwide. This global reach underscores the universal appeal of biomechanical principles in sports and the need for a comprehensive understanding of human movement. Furthermore, the collaborative spirit of sports biomechanics, involving experts from physiology, engineering, medicine, and coaching, has led to comprehensive strategies for athlete development and injury prevention. This confluence of knowledge and expertise has charted new paths for inquiry and application in the field.

Conclusively, the last twenty years mark a period of significant advancement in sports biomechanics, characterized by a broadened scope, integration of cutting-edge technologies, and substantive contributions to the realm of athletic performance and safety. This review not only highlights the robust nature of sports biomechanics as a field but also its ongoing potential to redefine the contours of sports science and enhance the athletic journey on a global scale. The advent of technology and computational tools has revolutionized sports biomechanics. Researchers have increasingly relied on sophisticated equipment, including motion capture systems, force plates, and computer simulations, to analyze sports movements with unprecedented precision. This shift has empowered scientists to explore complex biomechanical questions and provide practical insights for sports performance optimization.

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Conflict of interest

The authors declares that there is no conflict of interest in this study.

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Визначення тенденції розвитку досліджень у галузі спортивної біомеханіки за останні 20 років: Бібліометричний аналіз наукових публікацій у журналах, включених до наукометричної бази даних Scopus

Мухамад Аріф Аль Арда[1ABCD], Нурхасан[1ADE], Дві Кахйо Картіко[1ADE], Чунг Бінг Янг[2ADE], Саукі Сава Бікалаван[1BCD], Айнун Зульфікар Різкі[1BCD], Севесті Віолін Вілудженг Херіста[1BCD]

[1]Сурабайський державний університет
[2]Національний університет імені Донга Хва

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

Реферат. Стаття: 11 с., 5 табл., 4 рис., 57 джерела.

Історія питання. Спортивна біомеханіка є важливою складовою тренування та фізичної підготовки спортсменів. Максимізації тренувального процесу можна досягти завдяки впровадженню спортивної біомеханіки. Протягом останніх років спостерігається значне зростання наукових досліджень, пов'язаних із галуззю спортивної біомеханіки.

Мета дослідження. Метою цього систематичного оглядового дослідження було проаналізувати тенденцію розвитку досліджень зі спортивної біомеханіки за останні 20 років.

Матеріали та методи. У цьому дослідженні застосовано бібліометричний підхід та систематичний огляд щодо наукових публікацій у журналах, включених до наукометричної бази даних SCOPUS з метою аналізу дослідницьких тенденцій у галузі спортивної біомеханіки.

Результати. Протягом двадцяти років було проведено 259 досліджень, які відповідали критеріям включення. Результати аналізу показали значне збільшення кількості опублікованих досліджень з плином часу, із загальною кількістю 2215 цитувань і середнім показником — 1237 цитувань. У дослідженнях основна увага приділяється біомеханічним принципам у контексті спорту, причому ключове слово «Біомеханіка» є найбільш домінуючим. Терміни «Спортивна Біомеханіка», «Людина» і «Спорт» також належать до категорії найпоширеніших ключових слів, що зустрічаються в дослідженнях. Крім того, зазначені дослідження охоплюють різні аспекти, пов'язані із рухом людського тіла, включаючи аналіз рухів, аспекти здоров'я та застосування технологій у спорті.

Висновки. Проведене дослідження забезпечує розуміння основних досягнень і ключових аспектів спортивної біомеханіки за останні два десятиліття, а також висвітлює різноманіття предметів досліджень в рамках цієї галузі.

Ключові слова: коучинг, спортивна наука, тренування, фізична підготовка спортсменів.

Information about the authors:

Al Ardha, Muchamad Arif: muchamadalardha@unesa.ac.id; https://orcid.org/0000-0002-9192-2072; Department of Physical Education, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Nurhasan: nurhasan007@unesa.ac.id; https://orcid.org/0000-0003-2790-5777; Department of Physical Education, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Kartiko, Dwi Cahyo: dwicahyo@unesa.ac.id; https://orcid.org/0000-0002-6727-0879; Department of Physical Education, Health and Recreation, Faculty of Sport and Health Science, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Yang, Chung Bing: yang.cb.ndhu@gmail.com; https://orcid.org/0009-0002-0949-1902; Department of Physical Education and Kinesiology, National Dong Hwa University, No. 1, Section 2, Da Hsueh Rd., Shoufeng, Hualien 974301, Taiwan.

Bikalawan, Sauqi Sawa: sauqisawa.20040@mhs.unesa.ac.id; https://orcid.org/0000-0003-2477-2382; Department of Physical Education, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Rizki, Ainun Zulfikar: ainun.20015@mhs.unesa.ac.id; https://orcid.org/0009-0006-7025-7209; Department of Physical Education, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

Herista, Sevesti Violin Wilujeng: sevestiviolin.20013@mhs.unesa.ac.id; https://orcid.org/0009-0003-7975-3776; Department of Physical Education, Universitas Negeri Surabaya, Jl. Lidah Wetan, Lidah Wetan, Kec. Lakarsantri, Kota SBY, Jawa Timur 60213, Indonesia.

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Review Article

Ascertaining the Effectiveness of Coordination Training Interventions in Enhancing Sports Performance: A Systematic Review and Meta-analysis

Ashwani Saini[1ABCD], Bipin Kumar Dubey[1BCD] and Rakesh Vishwakarma[2BD]

[1]Amity University
[2]Sikkim Manipal University

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

Corresponding Author: Ashwani Saini, e-mail: asaini@amity.edu
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Abstract

Objectives. The study aimed to analyze the effects of training programs that focused on various coordination exercises to improve the sports performance and coordination of athletes.

Materials and methods. An electronic review was conducted to compile the literature related to this issue, using Scopus, PubMed, Google Scholar and ProQuest databases. Following a systematic search, eleven studies carried out between 2014 to 2024 were considered appropriate for meta-analysis and were retrieved and analysed. The studies included were confined to different coordination interventions, such as balance, rhythm, agility, neuromuscular training, jump rope ladder exercises, spatial orientation, non-sports specific and proprioceptive training, ranging from 6 weeks to an annual macrocycle with participants (sub-junior and junior levels) from different sports.

Results. The meta-analysis revealed a small effect size improvement for balance training (E = 0.38; 95 % CI = -0.66-2.54; p = 0.25), a large effect size and significant enhancement for coordination and rhythm training (E = 2.2; 95 % CI= -0.98-1.45; p = 0.70). Additionally, it was noted a moderate effect size and substantial improvement for a specific coordinative ability training (E = 1.8; 95 % CI = -0.84-2.99; p = 0.00) when compared the experimental group with the control group. The results of 11 studies established a significant effect size of various coordination training interventions in improving motor coordination of athletes. However, the impact of these interventions on sports skills and performance remains limited and inadequate.

Conclusions. After a thorough analysis, it was concluded that various training regimens involving different stimuli, means and methods, comprising proprioceptive training, spatial training, motor rhythm training, neuromuscular training, balance training, coordination training drills using ladders, wobble board, bosu balls, trampoline and dynamic games, as well as non-specific sports training with basic exercises, have been found to be effective in enhancing motor coordination and sports skills.

Keywords: systematic review, training, sports, coordination.

Introduction

Sports is a multifaced phenomenon which is governed by several physical, mental and technical components. Sports performance depends on the efficiency and effectiveness of motor Coordination which an athlete performs during a competition. Coordinative abilities and its implication in sports has been an area of concern for research scholars and scientists. Coordinative abilities can be classified into several categories such as orientation ability, rhythm, balance, reaction time, coupling and adaptation. These abilities put together not only influence the execution of motor movement and sports skills but also provide a stronger base for other abilities like strength and power (Mitrousis et al., 2023). Centre nervous system receives an impetus either from an external or internal stimuli to perform any movement, contracting skeletal muscle. Suitable training can enhance and develop this mechanism. Although several studies indicated the importance of coordinative ability in sports, sports specific coordination varies across sports disciplines. However, the effect of a sports specific coordination training is still uncertain and under investigation (Latino et al., 2021).

While performing technical skill in open – skills – oriented sports such as football, volleyball, tennis and badminton, a state of equilibrium is essential for better performance

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and to reduce errors. Moreover, in the close – skills – sports also balance plays a decisive role. Balance abilities have both static and dynamic versions that affect not only stability but also the execution of sports skills. As long as players remain stable and focused, they tend to perform better and demonstrate higher quality of playing ability. Several studies reported that balance training was found to be effective in promoting overall stability and better performance in sports (Cè et al., 2018; Lu et al., 2022; Mitrousis et al., 2023).

Another vital factor that plays a key role in sports context is rhythm which requires an external stimulant to execute controlled and consistent motor movement. Racquets sports and other team sports also emphasized on the development of rhythmic ability in young athletes. Several studies formulated and implemented rhythmic training which was found to be effective in improving the perception, reception and execution ability of young children (Söğüt et al., 2012; Yin et al., 2023).

Agility is another essential prerequisite which has a strong contribution in sports performance. It is the ability to change direction and to utilize the right muscles at a right time during the sports performance. In this context Shi et al. (2023) and several other investigators have studied the effect of agility training and sport performance. These studies reported meaningful impact of ladder training and agility training on sport performance (Bhisaji Pawar & Borkar, 2018; Malwanage et al., 2022a; Yüksel & Aydos, 2019)

Researchers have investigated the effect of various innovative modalities for instance proprioception and neuromuscular training on sports skills and coordinative abilities. These experiments have utilized innovative training protocol and innovative apparatus to inculcate better motor coordination and broader proprioception in the athletes (Blasco et al., 2024; Vasconcelos et al., 2023; Zhao et al., 2021).

Undoubtedly, better coordination led to better sports performance however, there is yet another issue that needs clarification and that is whether the coordination training have a direct impact on the sports skills or not. There are many studies which indicated the influence of coordination training in improving coordinative skills of an athlete, however its direct impact on sports skill is still uncertain. Many studies reported partial or small significance of these training modules on sports skills. In contrast, a few studies revealed that there was no significance of coordination training on sports skills (Formenti et al., 2021; Knobloch et al., 2005; H.-G. Lee, 2021; Peker & Taskin, 2016; Vișan et al., 2023).

To best of the author 's knowledge no systematic review and meta-analysis have been conducted so far regarding the effect of coordination interventions of various types in improving sports skills and enhancing the coordinative abilities of an athletes. Therefore, keeping this context in mind this study was proposed to analyse the effect of different coordination interventions in enhancing sports performance and coordinative abilities of the sports person.

Materials and Methods

Database and Search Profile

The literature related to the study was accessed using several electronic data bases primarily Pub med, Scopus, google scholar and ProQuest. Key words included "coordination training" "balance" or "footwork" or "coupling" or "adaptation" or "hand eye coordination" or "agility", "orientation" or "rhythmic" or "reaction time" and training or" intervention" and sports person or "athlete" were utilized. Additionally, the search was confined to last 10 years, articles published from Jan, 2014 to Jan, 2024, and it was also limited to human participants and scholarly journals. Once the articles were identified the cited references were also take in consideration for additional search. The search was also restrained to the English language literature only.

Eligibility criteria

Popular "PICOS" strategy was utilized to retrieve and to access articles, which includes participants, Interventions, comparison, outcome and study designed (Moher et al., 2009). Table 1. disclose the inclusion and exclusion criteria in details. This review was chiefly restricted to the effect of various coordination training on sports performance and improving coordination of athletes. The PRISMA flow chart figure1. underline the flow of the exclusion and inclusion of the studies retrieved and accessed in the present study with specific rationale.

Methodological Quality Assessment

Methodological quality of the included studies was ensured with the help of PEDro scale, which is a rating scale from ranges from 1 to 10 (de Morton, 2009). Higher rating reflects better methodological quality of training intervention and research paper. Two authors (AS & BD) have independently completed the quality check of methodology for every single study. However, in case of any disagreement, it was resolved with the consensus form third author (RV).

Data Extraction

A total of 145 studies were initially extracted from the electronic data based and out of which 69 studies were excluded based on the title. 76 studies were screened for further data extraction and out of which another 65 were excluded because of inclusion criteria and finally only 11 studies meet the inclusion criteria. The data was extracted from these studies and a summary of which is presented in table 2 that includes the objective & design, Sample & analysis method and outcome of the study.

Statistical Analysis

According to the guidelines of the Meta analysis minimum of three studies were required to compute the effect size and meta-analysis for the literature review. The Der Simonian and Laird (DL) model of effect size and meta-analysis was applied with the help of cumulative difference between the means, standard errors and Hedges's g across the various study and tua-T2 squared was computed to understand the heterogeneity amongst the groups. Effect size was computed while keeping the confidence interval at 95 %. and interpreted as <0.2 trivial, 0.2-0.6 low, 0.6-1.2 modeate, 1.2-2.0 large, 2.0-4.0 very large and 4.0> extremely large. Figure 2 Forest plot was created to showcase the effect size of cumulative difference in means of training groups and control groups Forest plot values are shown as effect size

Table 1. Inclusion and exclusion criteria utilized in the systematic review

Category	Inclusion criteria	Exclusion criteria
Population	Sports person across all disciplines regardless of training age, gender and playing level.	Non-sports persons
Intervention	Coordination training interventions focusing on, balance, footwork, coupling, adaptation, hand eye coordination, agility, orientation, rhythmic and reaction time workout	Training program that does not employ the coordination training interventions.
Comparison	At least have one training and control group design to determine and to compare the significance of effect.	One group study design or non-existence of control group
Outcome	Impact of training intervention on coordinative abilities such as balance, orientation, agility, rhythm, adaptation, footwork, hand eye coordination	Lack of initial or post data
Study design	Experimental design	Nonexperimental design

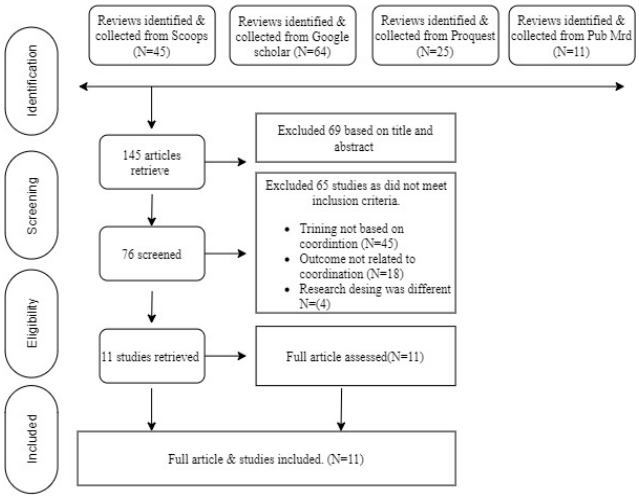

Fig. 1. PRISMA inclusion/exclusion flow diagram

(std. diff in means) with 95 % confidence interval (CI). Black square indicating the individual studies, and their size depict their relative weight, whereas rhomboid shows the summary value. whereas figure3 funnel plot was prepared to showcase the publication bias in the studies.

Results

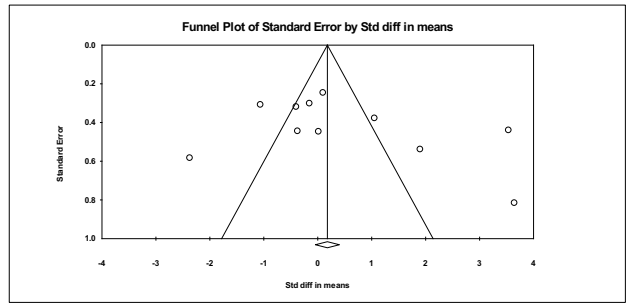

Fig. 3. Funnel plot indicating the publication bias

Discussion

The systematic review and meta-analysis provide valuable insight about different types of coordination training programs and their impact on sports skills as well as coordinative abilities. Although there are limited reviews in this area, the overall results of 11 studies demonstrates a significant effect size (Figure2) of various coordination training interventions in improving coordinative abilities such as static and dynamic balance, motor competency,

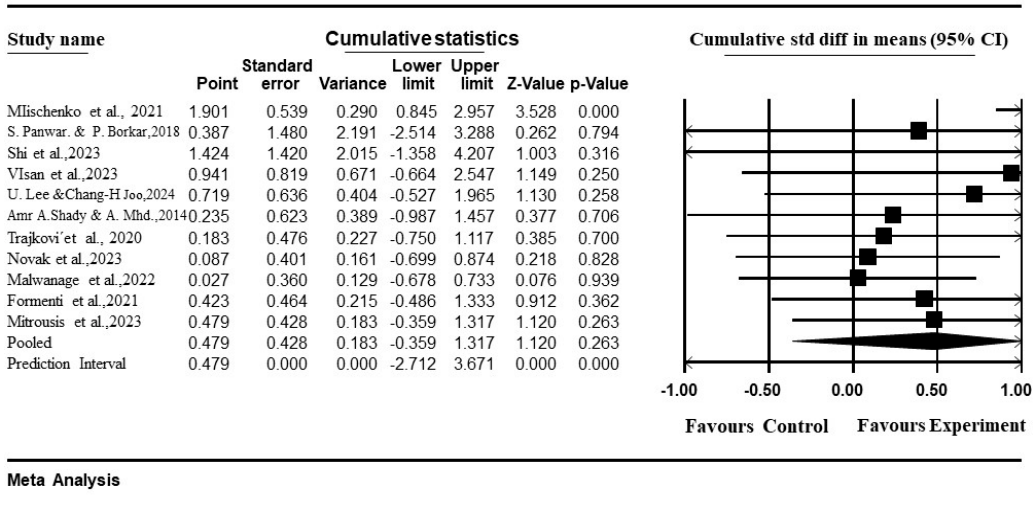

Fig. 2. Forest plot showing comparison of cumulative standard difference in mean

Table 2. Included Studies on effect of various Coordination interventions on sports performance and coordination of athletes

Authors	Study -Objective & Design	Sample size & analysis method	Outcome and conclusions
Mischenko et al., 2021	Proposed a new methodology for increasing coordination ability in acrobatics sports for females; Two groups, training and control.	N = 20 each in Training and control group; vestibular stability and dynamic coordination were tested.	Result shown significant improvement in coordinative abilities & technical readiness in annual macro-Cyle ; 7 to 10 years is the most suitable age for improving coordinative abilities.
Smurti Pawar & Pradeep Borkar, 2018	Ladder training drills to improve the agility of kabaddi female players; 6 weeks training program with one experimental and one control group.	N = 24 each in Training and control group; agility t test was conducted.	Training group improved significantly in agility; Ladder training for 6 week was effective for enhancing agility.
Shi et al., 2023	Jump rope training for improving dynamic balance and stroke ability of tennis players; 12-weeks training for 3 days a week.	N = 8 in each training and control group; single leg stability test & hitting ability were tested.	Jump rope training and sequencing the rope training with technical training helps to competitive level of tennis players.
Visan et al., 2023	Coordinative ability drills including, ladders, dribbling, running, dynamic games were implemented on young football players; annual macro cycle with one experimental and control group.	N = 21 in both groups; T test (blaze pod technology) and adam test was used for assessment coordinative abilities of the football players.	Intervention program has helped in improvement of agility test on football players.
U-Yeong Lee & Chang-Hwa Joo, 2024	To analyse the effect of proprioceptive training on skill and physical fitness component e.g. balance and agility for young football players ; 8-week training for 2 days a week using balance trainer and bilateral exercises.	N = 10 in training group and N = 9 in control group; Balance measurement system consisting of a board MFT challenge disc 2.0, Austria was used, arrowhead test for agility	Proprioceptive training facilitates balance and agility, however no significance improvement in shooting, dribbling and shot passes; addition in the frequency and time of proprioceptive training was recommended.
Amr Ali Shady & Mohammad Abdel Sattar Mahmoud, 2014	To find out the effect of spatial orientation and motor rhythm training on motor speed and skill of football players; 8-week training for 3 days a week with experimental and control groups.	N = 13 each in both experimental and control group; spatial orientation (turning to touch the colour test), motor rhythm ability (drobe,1999), motor speed and skill ability (shooting, passing and dribbling were assessed.	Spatial orientation and motor rhythm training enhanced the motor speed and skill level of junior football players.
Trajkovic' et al., 2020	Neuromuscular training was implemented to ascertain its effect on motor competence and skill performance of volleyball players ;10-week training with training and control group.	N = 32 in training and 34 in the control group; The Körperkoordinationstest für Kinder (KTk) Test to know the motor competency and modified t Test, 10m sprint, plank, vertical jump and medicine ball throw was tested.	Neuromuscular training not only helped in the improvement of motor competency but also the physical skill of volleyball players. No improvement in plank performance.
Novak et al., 2023	To assess the effect of balance training program on the player's balance and technical skill of the adolescent soccer players;8-week training program with training and control group.	N = 17 in training group and 15 in the control group; Static and dynamic balance and technical skills (passing, shotting with dominant and nondominant leg) and juggling were assessed.	Balance training has helped in improvement of static and dynamic balance and shooting with dominate leg. However no significant improvement in other variables.
Malwanage et al., 2022	To find out the effect of balance training on static and dynamic balance and sports specific foot work performance ; 8-week training with frequency of 2 days a week with training and control group.	N = 12 in intervention group and 8 in control group; Static balance and dynamic balance was tested with unipedal stance and stat excursion test respectively while the sports specific footwork was assessed with shuttle run and push off time during stroke play.	Balance training has enhanced the dynamic balance and shuttle run time while no improvement in the other variables; It was recommended to have balance training more challenging by increasing the base of support and higher centre of gravity, removing the visual feedback and changing the training surface.
Mitrousis et al., 2023	To analyse the effect of balance training on the balance and sports skills of young football players by using Bosu balls, wobbles boards, agility ladders, mini trampoline balance beam and obstacle;8-week training with the training and control group; control group was given a placebo training.	N = 17 in experimental group while only 15 participants in the control group; Jhonson and nelson test for static balance and Lafayette balance device with wooden board for dynamic balance and sports skills such as passing, shooting, juggling and dribbling were assessed.	Balance training has helped in the improvement of dynamic balance and shooting skills; No improvement in other tested variables but it was recommended to consider the gender, playing position and different competition level for better results.
Formenti et al., 2021	To investigate the influence of non-sports specific and sports specific training on the skills and perceptual response and general motor coordination of football players:10-week training with three groups, non-sports specific, sports specific and control group were utilized.	N = 26 in non-sports specific group and 27 participants in sports specific group and 26 in control group; Harre circuit test for motor coordination, Y-balance test and linear dribbling test was used for the skill assessment.	Non-sports specific training was significantly better than sports specific training in Haree test and Y-balance test, however no difference in dribbling; integration of non-sports specific training was recommended.

agility, motor coordination, rhythm, single leg and vestibular stability (Bhisaji Pawar & Borkar, 2018; Johann et al., 2016; U.-Y. Lee & Joo, 2024; Lu et al., 2022; Shi et al., 2023; Söğüt et al., 2012; Yin et al., 2023). However, the impact of these training methods on sports skills and performance is still confined and inadequate. Among these studies that provide data for coordinative abilities, the notable large benefit effect was reported for various playing level (from sub junior to junior), primarily adolescent (i.e. 9 to 16 years) and different genders. Majority of studies were confined to 8 to 12 weeks of training with 2 to 3 days of training days incorporating both the coordinative abilities and skill training of the sports person of multiple sports (i.e. Badminton, football, volleyball, kabaddi and tennis). Additionally, literature review reported a few longitudinal studies for an annual macro cycle with several phases of training (Mischenko et al., 2021).

Balance and coordinative abilities

Balance is one of the crucial coordinative abilities that play a key role in sports performance and efficient motor movement. The literature review provides evidence that balance training provides a small to large effect size improvement in both static and dynamic balance and facilitates skill development. Novak et al. reported a small effect size (0.38) (Novak et al., 2023) noting improvement in both static and dynamic balance and dominant leg shooting of football players yet not much substantial improvement in other skills components such as passing and dribbling of football players. Another study by Malwanage et al. (2022) highlighted a similar trend with a small effect size of 0.33. Even though the dynamic balance and shuttle run performance improved significantly, no improvement in static balance of the football players was reported. These studies suggested that the balance training should be more complex in nature with integrating lower base of support and higher centre of gravity. Additionally, training can be made more challenging and yield better results by incorporating varied visual feedback and more specific training modules keeping in view the gender, training level and position of the players. On the other hand, Mitrousis et al. reported a large effect size (Figure 2) and improvement in coordinative abilities (Mitrousis et al., 2023a). Optimum utilization of appropriate equipment such as Bosu balls, wobbles boards, agility ladders, mini trampoline balance beam and obstacle may further enhance the coordinative abilities of players. Though a traditional training method, jump rope training can facilitate static and dynamic balance and support the technical skills of the player. Shi et al. (2023) reported large effect size with significant results of jump rope skipping on the single leg stability and skill level (Yin et al., 2023). Sequencing of jump rope and integrated it with technical training could yield better results

Rhythm and motor competency

Motor competency and rhythm plays a pivotal role in sports and achieving desired performance during the competition. The central nervous system regulates rhythm which relies on an external stimulant while motor competency utilized the optimum activation neuromuscular junction. Among all studies, few studies reported a significant influence of neuromuscular, rhythm and coordinative ability training on motor competency and rhythm of sports person. Trajkovic' et al. (2020) reported a large effect size and significant result of neuromuscular training on the motor competency of the volleyball players (Trajković & Bogataj, 2020).The Körperkoordinationstest für Kinder (KTk) test was used to assess motor competency and 10 weeks of neuromuscular training may enhance the motor competency and physical skills of the players. This training included fundamental exercises like deep squats, four-way jumps, medicine ball throw, wall sits, box jump, hurdle jumps, and agility ladders which led to significant improvement in the motor competency of the players.

Another study by Amr Ali Shady and Mohammad Abdel Sattar Mahmoud (2014), also highlighted some benefits of spatial orientation and motor rhythm for sports persons (Shady & Mahmoud, 2014). An 8 week-long training that uses spatial orientation and motor rhythm training reported a large effect size and significant improvement in the spatial orientation and motor speed of a sports person. These findings are of great importance as if a player improves these fundamental abilities they can participate in strength and more complex conditioning programs.

Agility and coordinative abilities

Agility has been a vital component of sports training and performance enhancement programs. Change of direction with precision and efficient utilization of desired muscle group is essential in achieving success and consistency in sports performance. Smurti Pawar and Pradeep Borkar (2018) demonstrated that 6 week of ladder training significantly improved agility and performance in the volleyball players. Therefore, Ladder training should be an integral part of the training regime for sports persons. To contrast another study by Visan et al. (2023) reported small size effects of coordinative training that utilized ladder, dynamic games and dribbling for football players (Vișan et al., 2023). However, it was suggested that 8 to 10 year is the most suitable training age to train these abilities. Furthermore, U-Yeong Lee and Chang-Hwa Joo (2024) emphasised the effectiveness of proprioceptive training. This study used a MFT challenge disc 2.0, Austria for balance and arrowhead test for agility (U.-Y. Lee & Joo, 2024). The training regime incorporated exercises with ball and without ball for instance standing with one leg and single leg heading, squat, lunge, jumping and swing forward and back without ball. Increase in time of training and frequency of the training was suggested to foster better results.

Sports skills and coordination training

Indeed, coordination influence the sports skills and technical efficiency of the players. Mastery of sports skills largely depends on the level and proficiency in coordinative abilities. Surprisingly, all these studies reported varying effect sizes for coordination training in sports skills.

Mischenko et al. (2021) proposed a new methodology for improving coordinative ability in acrobatic sports finding a large effect size of coordination training on vestibular stability, dynamic coordination and technical readiness. This study was completed in an annual macro-cycle that included the skateboard, agility ladder, trampoline and Bosu

hemisphere in active game. Another study by Formenti et al. (2021) which examined the effect of sports specific and non-sports specific training on the coordination and skill of football players. Interestingly, non-sports specific training helped in improvement of perceptual response, motor coordination and balance of football players (Formenti et al., 2021). This non-sports specific training regime include balance drills, SAQ drills and jump rope drills. This means that balance work on unstable surface, trampoline, basic skill exercise (split steps, line drills, lateral drills, hopscotch, in and out drills) and jumps rope exercise (basic bounce steps, alternate bounce and doubles basic bounce) were found suitable for improving the sports skills and coordinative abilities. This may be due to non-sports specific stimuli for the athlete and enjoyment of the innovative exercise routine. Still there is a scope to understand the implication of non-sports specific training on the enjoyment and development of sports skills and enhancement of coordinative abilities.

Limitation

A key limitation of this literature review was inclusion of a lower number of participants in the study which is why it produced a lower level of effect size and lower power in the cumulative statistics and resulted in standard error and false negative. Majority of the study were conducted over 8 weeks and lower frequency either twice or thrice day a week which is a shorter duration to produce significant effects on motor abilities This is an essential factor in all sports-oriented training. Future research should focus on longitudinal studies to achieve more robust results. Not initiating the coordinative abilities training at an early age as old as 8 to 10 years is another limitation of this meat-analysis, which was revealed in many studies. Formulation of training programs according to the age, gender and training level of the athletes may warrant encouraging results.

Conclusion

The meta-analysis suggested that coordination training which utilized diverse modalities including neuromuscular training, rhythm training and proprioceptive training were significant in improving sports skills and coordinative abilities in sports persons. Further the current literature review advocates the use of traditional methodologies for instance ladder training, jump rope and non-sports specific basic exercise along with innovative modern technological bases apparatus to produce effective results. This diverse approach helps in improving the sports skills as well as the coordinative abilities of athletes. Additionally, this meta-analysis recommended that basic sports training and agility training also enhanced the coordinative abilities and sports skills of a sports person. Strength and conditioning coaches should integrate innovative and basic coordination training mean and method at an early age on or before 8 to 10 years to induce better sports performance. However, formulation and implementation of the longitudinal studies and orientation of sports specific and non-sports specific coordination training may warrant improved perceptual skill, motor competency and motor coordination of athletes. Further, future research should use different training terrain and latest technologies to boost coordinative abilities and to produce significant results.

Conflict of Interest

Authors declare no conflict of interest regarding this paper.

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З'ясування ефективності інтервенцій з координаційного тренування щодо покращення спортивної результативності: Систематичний огляд та метааналіз

Ашвані Саіні[1ABCD], Біпін Кумар Дубей[1BCD], Ракеш Вішвакарма[2BD]

[1]Університет Аміті
[2]Сіккімсько-Маніпальський університет

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

Реферат. Стаття: 8 с., 2 табл., 3 рис., 33 джерела.

Мета дослідження. Метою дослідження було проаналізувати вплив тренувальних програм, сфокусованих на виконанні різноманітних координаційних вправ, щодо покращення спортивної результативності та координації спортсменів.

Матеріали та методи. З метою збору літературних джерел, пов'язаних з вивченням зазначеної тематики, проведено огляд електронних публікацій із використанням наукометричних баз даних Scopus, PubMed, Google Scholar та ProQuest. Після систематичного пошуку було отримано та проаналізовано одинадцять досліджень, проведених у період з 2014 по 2024 рік, які вважалися доцільними для здійснення метааналізу. У включених дослідженнях розглядалося проведення різних тренувальних інтервенцій, спрямованих на розвиток координації, як-от тренування для розвитку рівноваги, ритму, спритності, нервово-м'язової системи, виконання комплексу вправ зі стрибків на скакалці та із використанням координаційної драбини (швидкісної доріжки), вправи для розвитку просторового орієнтування, неспортивне специфічне та пропріоцептивне тренування, тривалістю від 6 тижнів до річного макроциклу із залученням учасників (субюніорського та юніорського рівнів) з різних видів спорту.

Результати. За результатами метааналізу виявлено незначне покращення розміру ефекту щодо тренувань з розвитку рівноваги (E = 0,38; 95 % ДІ = -0,66-2,54; p = 0,25), великий розмір ефекту та суттєве підвищення показників щодо тренувань з розвитку координації та ритму (E = 2,2; 95 % ДІ = -0,98-1,45; p = 0,70). Крім того, відзначено помірний розмір ефекту та істотне поліпшення показників щодо тренування специфічних координаційних здібностей (E = 1,8; 95 % ДІ = -0,84-2,99; p = 0,00) у порівнянні експериментальної групи з контрольною групою. Згідно з результатами 11 досліджень встановлено значний розмір ефекту при застосуванні різних інтервенцій з координаційного тренування щодо покращення рухової координації спортсменів. Однак вивчення впливу вищевказаних інтервенцій на спортивні навички та результативність залишається обмеженим і недостатнім.

Висновки. Після проведення ґрунтовного аналізу встановлено, що застосування різних тренувальних режимів, що передбачає залучення різноманітних стимулюючих чинників, засобів і методів, а саме: пропріоцептивні тренування, вправи для розвитку просторового орієнтування, тренування рухового ритму, вправи для розвитку нервово-м'язової системи, тренування на рівновагу, комплекс вправ на координацію із використанням драбини, воббл-борду (балансувальної дошки), балансувальних півсфер, батуту, динамічні ігри, а також неспецифічні спортивні тренування з базовими вправами, довело свою ефективність з точки зору покращення рухової координації та розвитку спортивних навичок.

Ключові слова: систематичний огляд, тренування, види спорту, координація.

Information about the authors:

Saini, Ashwani: asaini@amity.edu; https://orcid.org/0000-0002-8283-0731; Amity School of Physical Education and Sports Sciences, Amity University, Sector 125, Express way Noida 201313, Uttar Pradesh, India.

Dubey, Bipin Kumar: bkdubey@amity.edu; https://orcid.org/0000-0003-1392-8222; Amity School of Physical Education and Sports Sciences, Amity University, Sector 125, Express way Noida 201313, Uttar Pradesh, India.

Vishwakarma, Rakesh: rakesh.v@smit.smu.edu.in; https://orcid.org/0000-0002-9298-8970; Department of Physical Education and Sports, Sikkim Manipal Institute of Technology, Sikkim Manipal University, Majitar, Rangpo, Sikkim 737136, India.

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Review Article

Unveiling Current and Future Trends in the Implementation of Teaching Games for Understanding in Primary School: A Bibliometric Analysis

Irfan Octavianus[1ABCDE], Uray Gustian[2ABCDE] and Andika Triansyah[2ABCDE]

[1]Universitas Negeri Padang
[2]Universitas Tanjungpura

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

Corresponding Author: Irfan Octavianus, e-mail: irfanadhe@fik.unp.ac.id
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Abstract

Background. Physical Education (PE) often focuses on sports skills through command-based teaching methods, which can lead to students struggling to understand and effectively play games. To address this issue, Teaching Games for Understanding (TGfU) has been introduced as a more effective approach to enhance tactical comprehension and gameplay skills, while also increasing student engagement in physical activities.

Objectives. This study aimed to identify current research trends and future potential for TGfU implementation in elementary school PE through a bibliometric analysis.

Materials and methods. A bibliometric approach was used by analyzing 977 documents from the Scopus database published between 2015 and 2024. The data was analyzed using VOSviewer to map bibliographic networks and conduct keyword analysis. A science mapping approach was applied to identify emerging research trends and predict the future of TGfU implementation.

Results. The analysis revealed that TGfU implementation effectively improves physical activity, motor skills, and the well-being of elementary students. However, further research is needed to fully understand and validate these findings. Current trends emphasize the importance of PE in enhancing physical activity, motor skills, and student well-being through the TGfU approach. Future trends point towards developing PE curricula that undersore the integrated use of TGfU and holistic approaches.

Conclusions. Implementing TGfU in elementary schools holds great potential for improving physical engagement, tactical skill development, and students' psychological well-being. Challenges include optimizing the role of teachers as facilitators and adapting the curriculum for broader TGfU application. Further research is required to validate the application of the TGfU model in PE curricula and to develop approaches relevant to the needs of elementary students.

Keywords: physical education teaching, teaching game for understanding, primary school, future research trends.

Introduction

PE has traditionally been taught using a command-based teaching style focused on sports content, but it is now shifting towards the application of decontextualized sports techniques (Kirk, 2016). As a result, many students struggle with learning, and they also find it difficult to play during games (Harvey et al., 2018). This traditional paradigm centers PE instruction around multi-activities and sports techniques, which leads to students developing fewer skills, with short teaching sessions and pursuing benefits that cannot be achieved by all student profiles (Casey & Kirk, 2020). In response, experts have introduced an alternative model for teaching team games in PE, known as Teaching Games for Understanding (TGfU). This model allows students to learn games by focusing on their understanding of how to play and on skill development (Papagiannopoulos et al., 2023).

TGfU is described as an alternative to content-oriented learning models, using an actual gameplay approach in its implementation (Memmert et al., 2015) and enhanced students' ability to identify tactical problems that arise during games and to respond appropriately (Mitchell et

al., 2020). This is recommended as an effective approach to promoting motor skills (Dania & Harvey, 2020). This model is particularly effective in primary schools (García-López et al., 2019) as students are still developing fundamental movement skills, and playing games provides an engaging way for them to learn (Goodway et al., 2019). Furthermore, its can be used as a method to enhance motivation in students who may be less engaged with physical education lessons (García-González et al., 2020).

Several studies have demonstrated its effectiveness in developing tactical knowledge, the ability to evaluate game situations, and in fostering tactical reasoning (Harvey et al., 2020). It has also been shown to increase engagement, motivation, and enjoyment (Batez et al., 2021), as well as improve moderate physical activity levels during lessons (Wang & Wang, 2018). The application of TGfU has also been found to enhance decision-making, skill execution, successful game performance, the number of decisions made, game involvement, and the intention to remain physically active (Barquero-Ruiz et al., 2021). It further aids in the acquisition of students' critical thinking skills (Barnabè et al., 2023) and considered more suitable than direct instruction for increasing light physical activity (PA) levels during sessions (Sierra-Ríos et al., 2020). These advantages provide a strong basis for teachers to consider using the TGfU model in PE lessons, particularly in primary schools.

The main challenges for teachers still revolve around planning, developing the role of the facilitator to support learning, and providing sufficient time for applying knowledge during games (Thomas et al., 2013). Additionally, studies have often focused on secondary classes rather than primary classes and have primarily aimed at improving motor skills without assessing students' understanding. On the other hand, PE teachers continue to face challenges or difficulties when using the model (Harvey, 2016; Papagiannopoulos et al., 2023), as well as a lack of widespread adoption of TGfU by teachers (García-López et al., 2019). Many PE teachers still fail to teach games effectively and comprehensively, remaining focused on students' skill development (Ward & Griggs, 2011) and improving tactical understanding and decision-making (O'Connor et al., 2017). The practice of implementing TGfU remains limited and must be adapted to the PE curriculum in each school (Harvey, Cope, et al., 2016) and should be designed to suit the context, aligning with the characteristics of students and the school environment (Morales-Belando et al., 2022).

Given the challenges faced by teachers, it is crucial to conduct studies to understand the factors influencing these issues and to identify alternative solutions for resolving them, as well as to explore current themes surrounding TGfU implementation. Several studies have been conducted to examine the implementation of TGfU using systematic review methods. Ortiz et al. (2023) reviewed 13 articles on the effects of it interventions on game performance and psychosocial variables. Robles et al. (2020) reviewed 13 studies on the impact of technical and tactical approach interventions on skill performance and decision-making, including an assessment of how the management style of the teacher or coach affects these outcomes. Furthermore, Morales-Belando et al. (2022) reviewed 20 studies from a practice-based perspective on how researchers documented their interventions, focusing on the characteristics of teaching and learning implementation and their connection to learner outcomes. Yan et al. (2023) reviewed 17 studies on the impact of game-based approaches on game performance, fundamental movement skills, health-related measures, and PA outcomes in children aged 5 to 12 when implemented in primary school PE settings. These studies highlight important content related to it implementation, the approaches used, the results obtained, and gaps for further research.

However, based on the author's understanding and knowledge, no studies have yet been found that use bibliometric analysis. To bridge this gap, bibliometric analysis is employed to complement traditional literature reviews through an objective approach to understanding the current research landscape and future trends (Saini et al., 2022). This bibliometric analysis study comprehensively examines the scientific literature on it. The aim of this bibliometric study is to explore the literature on TGfU implementation using bibliographic coupling analysis and to identify potential current and future research trends through co-word analysis. The study explores emerging and trending themes while predicting future trends. It presents network visualisations in cluster analysis using science mapping techniques, producing a temporal structure and topology of topics. The results are expected to reveal the intellectual structure by understanding its development over time and the richness of research streams.

Materials and Methods

Bibliometric Approach

The bibliometric approach is a scientific method that assists academics in analysing literature by summarising and synthesising it (Donthu et al., 2021). Additionally, bibliometric analysis serves as an essential tool for systematically investigating publication patterns based on existing literature by combining quantitative data and qualitative interpretation (Paul & Barari, 2022). Furthermore, bibliometric analysis is used to complement the analysis of the evolution, current state, and future trends in scientific fields (Mulet-Forteza et al., 2022) and supports the prioritisation of research, processing, and analysis at various levels of complexity (Mejia et al., 2021).

Bibliometric analysis is conducted using two approaches: performance analysis, which examines the number of publications, citations, and publication productivity, and science mapping, which identifies the knowledge structure based on relationships between studies through network visualisation (Tiberius et al., 2020). In this study, bibliometric analysis is carried out using a science mapping approach to identify potential current and future research trends through co-word analysis. This involves interpreting the current state and forecasting future trends in published literature through bibliographic coupling and co-occurrence analysis.

Research Design and Data Collection Procedure

The Scopus database was utilised to search for relevant documents related to the implementation of TGfU. The reason for using Scopus is that it is a popular database among researchers globally (Khan & Muktar, 2020) and allows

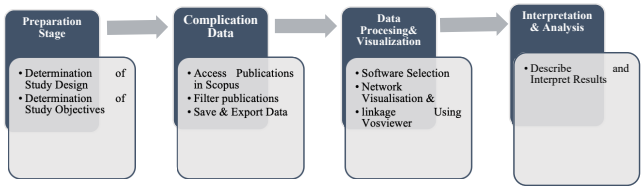

Fig. 1. Flowchart of Study Design

for the export and analysis of documents for bibliometric studies (Zyoud et al., 2024). The search results were analyzed using the publication mapping tool VOSviewer version 1.6.20 to create publication maps based on text corpora or citation networks, providing key insights into the content of the documents (Sinkovics, 2016). Therefore, in this study, VOSViewer was used to visualise the bibliographic coupling and co-occurrence network maps, as illustrated in Figure 1.

The document search was conducted on 4 September 2024, following the criteria outlined in Table 1. The search yielded 1,899 documents. These were then screened based on the publication date range of 2015-2024, document type as articles, finalised publications, published in journals, and written in English. After screening, 977 documents were obtained and further processed by exporting them in CSV format.

Table 1. Document Search Criteria

Criteria	Description
Source Database	Scopus
Search string	("physical education" OR "movement education") AND ("teaching games for understanding" OR "tactical games model" OR "step-game approach" OR "invasion games competence model" OR "game sense" OR "tactical decision learning") AND ('elementary school" OR "primary school"))
Search in	Title, abstract, & Keywords
Source & Document type	Jurnal & Article
Publication Language	English
Publication stage	Final
Dokumen yang diperoleh	977

Results

General Information

An overview and key insights from the documents obtained are presented in Table 2 and serve as the foundation for subsequent analysis. The documents related to the implementation of TGfU in primary schools were sourced from 319 publications, with an average annual growth rate of 3.35% and an average of 11.33 citations per year. The publications involved a total of 3,058 authors, with a collaboration index of 4.21, meaning that more than four authors contributed to each published document. Additionally, there were 88 single authors responsible for publishing 99 documents. In total, the documents referenced 39,710 sources, and 2,181 unique keywords were used by the authors.

Bibliografic Coupling Analysis

Bibliographic coupling analysis is an extension of co-citation analysis, assuming that two publications share a connection if they reference the same sources (Donthu et al., 2021). Bibliographic coupling is a technique that assumes two publications share a connection if they cite the same references, with the degree of bibliographic linkage indicating the more references they share, thereby offering insight into current trends (Donthu et al., 2021). In this study, bibliographic coupling analysis was conducted using the same database of 977 documents, with a minimum citation count of 35 for each document, resulting in a threshold of 66.

Table 2. General Information

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2015:2024
Sources (Journals, Books, etc)	319
Documents	977
Annual Growth Rate %	3.35
Document Average Age	3.98
Average citations per doc	11.33
References	39710
DOCUMENT CONTENTS	
Keywords Plus (ID)	1922
Author's Keywords (DE)	2181
AUTHORS	
Authors	3058
Authors of single-authored docs	88
AUTHORS COLLABORATION	
Single-authored docs	99
Co-Authors per Doc	4.21
International co-authorships %	24.67
DOCUMENT TYPES	
article	977

The visualisation of the bibliographic coupling network, resulting from this analysis, is presented in Figure 2. The network visualisation reveals five clusters, represented by different colours: Cluster 1 (red), Cluster 2 (green), Cluster 3 (blue), Cluster 4 (yellow), and Cluster 5 (purple). Each cluster is interconnected. A qualitative interpretation was then conducted by the author, assigning labels to each cluster based on the emerging themes.

Cluster 1 (red) consists of 21 items labelled "the role of PE in enhancing PA to support healthy child development". PE plays a role in promoting healthy child development by increasing moderate-to-vigorous PA (MVPA) (Mooses et al., 2017). Therefore, it is important to boost MVPA and reduce inactive time (Tanaka et al., 2018). Meeting school PA guidelines can be achieved through comprehensive programmes, such as classroom-based physical activities prioritising the use of classroom space (Carlson et al., 2015). Additionally, strategies to enhance PA can involve using free time to engage in organised sports (Hebert et al., 2015). PA

programmes have a chronic impact on improving children's executive function, particularly when they include cognitive elements (Schmidt et al., 2015). However, limited time is a major barrier, so additional PA must be implemented in the classroom with short durations and easy-to-understand material for students (Van den Berg et al., 2017). In response to this issue, Riley et al. (2015) revealed that increasing school-based PA could be integrated into mathematics lessons, so PA is conducted in line with tasks in maths classes.

Cluster 2 (green) consists of 12 items labelled "learning strategies and interventions to enhance PA and student fitness in schools". Several studies have been conducted as efforts to increase student PA through learning activities. The integration of different teaching styles, known as multi-teaching styles and active reflection (MTA), can improve fitness, motor competence, enjoyment, and the amount of PA (Invernizzi et al., 2019). A study by Miller, Christensen, Eather, Sproule, et al. (2015) revealed that object control FMS proficiency and in-class PA in stage three students simultaneously improved through the program intervention The Professional Learning for Understanding Games Education (PLUNGE). Furthermore, learning that integrates health- and skill-related fitness components in primary schools can enhance aerobic capacity and muscle fitness in children (Faigenbaum et al., 2015). Additionally, PA programmes can be implemented through learning strategies that focus on FMS to improve children's motor skills and PA behaviour (Lee et al., 2020).

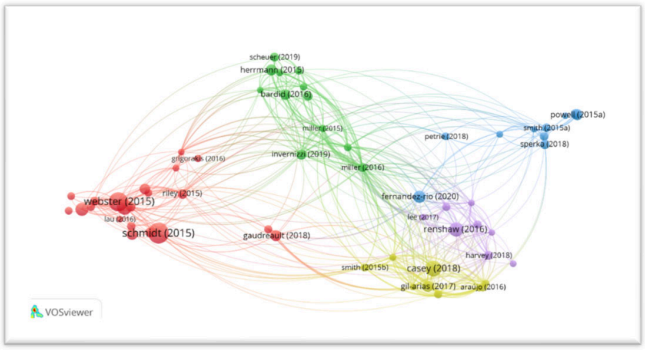

Fig. 2 Network visualization of bibliographic coupling

Cluster 3 (blue) consists of 10 items focusing on the role and actions of teachers in delivering lessons. A teacher must implement student-centred learning by considering the characteristics of their students, ensuring that the designed instruction truly accommodates student abilities (Petrie et al., 2018). Teachers play a key role in providing inclusive learning by making pedagogical modifications to ensure meaningful engagement in PE lessons for all students (Overton, 2017). As a profession, it is our responsibility to ensure that all students experience quality physical education programmes and that PE teachers work in ways that maximise the benefits for students (Dyson et al., 2016). However, teachers face challenges related to the shift towards outsourcing PE to commercial sports coaches, which de-professionalises the delivery of PE, worsening its implementation in primary schools (Jones & Green, 2017). These coaches often lack pedagogical knowledge, leading to difficulties in managing student behaviour and classroom management (A. Smith, 2015).

Cluster 4 (yellow) consists of 9 items labelled "empirical insight into using a MBP approach involving several models to teach physical education." To enhance student PA in PE lessons, teachers are encouraged to use the model-based practice (MBP) approach. Studies have shown that the Teaching Game Model (TGM) significantly increases students' MVPA (L. Smith et al., 2015). Furthermore, MVPA levels can be improved through Game-Centred Approaches (GCAs), which are recommended for PE and health objectives (Harvey, Song, et al., 2016). Additionally, implementing a hybrid TGfU/SE pedagogical model allows students to feel motivated, enjoy the competence, develop a positive image of sports for practice, experience greater enjoyment, and be physically active (Gil-Arias et al., 2017). Another study on TGfU implementation found that both students and teachers reported improvements in decision-making, technical execution, defence, support, game performance, game involvement, enjoyment, perceived competence, and the intention to be physically active (Morales-Belando et al., 2018). However, teachers still face challenges in adopting the MBP approach and need to shift their teaching philosophy (Casey & MacPhail, 2018).

Cluster 5 (purple) consists of 8 items labelled "the TGfU approach to enhance metacognitive behaviour and social constructivism in primary schools". TGfU is a pedagogical approach to teaching that is delivered through games (Harvey et al., 2018). This game-based approach can be used to enhance metacognitive behaviour in primary school students (Chatzipanteli et al., 2016). Furthermore, TGfU provides significant benefits from the motor-praxis framework as it fosters an understanding of game concepts, guiding motor behaviour, and systematically developing teaching practices (Martínez-Santos et al., 2020). The implementation of the TGfU approach can be facilitated through peer interaction, fostering social constructivism (Koekoek & Knoppers, 2015).

Co-word Occurrence analysis

The co-word occurrence analysis aims to break down the content of each thematic cluster and provide predictions for future research (Donthu et al., 2021). The co-word analysis examined 48 terms that met the threshold out of 3,754, with a minimum keyword co-occurrence of 30. The results yielded 15 keywords with the highest co-occurrence (Table 4), a network visualisation forming three clusters (Figure 3), and representative keywords for each cluster (Table 5). The qualitative analysis of each cluster is described as follows:

Cluster 1 (red) includes 22 keywords and is labelled "Enhancing Student Development through Comprehensive PE Programs in Primary Schools." This cluster highlights the significance of a well-rounded PE curriculum that not only focuses on physical skills and fitness but also integrates effective teaching methods, motivational strategies, and essential life skills to support holistic student development. The effective implementation of the primary school PE curriculum involves a holistic approach, addressing physical, cognitive, social, and emotional aspects while considering curriculum flexibility, local needs, and individual students (Mustafa et al., 2024). Pedagogical interventions such as game-based approaches, Mastery Teaching, and Sport Education have been identified as strong investments

across multiple domains (Dudley et al., 2022). Additionally, positive psychological changes can be effectively achieved by students through school-based physical education (Cho, 2020).

Cluster 2 (green) includes 13 keywords and is labelled "The Impact of Physical Fitness and Health Promotion on Academic Achievement and Psychological Well-being in Primary Schools." This cluster focuses on the interconnectedness of physical fitness, health promotion, and academic success, emphasizing how comprehensive physical education can enhance students' cognitive functions, psychological health, and overall academic performance. PA promotion through extracurricular activities significantly impacts academic achievement, mediated by various cognitive, psychological, and social factors (Zarazaga-Peláez et al., 2024). Efforts to improve students' psychological well-being can be implemented through various forms and durations of intervention, particularly for school students (Piñeiro-Cossio et al., 2021). One such intervention is integrating physical literacy into Active School Recreation, which positively affects physical fitness and academic achievement in children (Zhang et al., 2023). Additionally, multicomponent and combined PA interventions can improve psychological well-being and quality of life (Hale et al., 2021).

Cluster 3 (blue) includes 13 keywords and is labelled "The Role of PA in Developing Motor Skills and Managing Obesity in Students." This cluster highlights the importance of PA in early childhood for both boys and girls, focusing on how it enhances motor skills and helps manage body mass and obesity. Clinically, overweight and obesity can be reduced by improving cardiovascular fitness levels (Elagizi et al., 2020). Thus, promoting PA and fitness through school-based interventions equips students with knowledge about the content, quality, duration, and prioritisation of PA (Yuksel et al., 2020). School-based PA interventions are particularly effective strategies for preventing obesity in children aged 6 to 12 years (Podnar et al., 2021). Furthermore, increasing activity levels in preschoolers can be achieved through a multicomponent model (Coe, 2018).

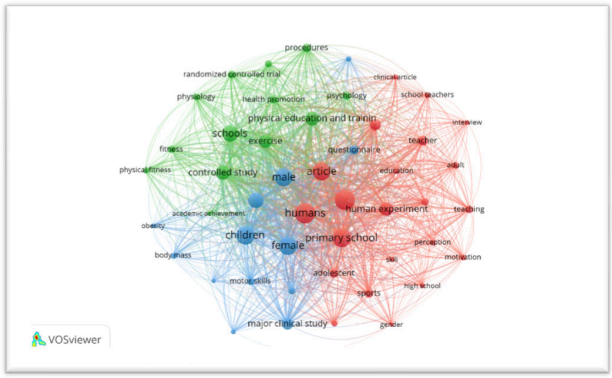

Fig. 3. Network visualization co-word occurence analysis

Table 3. Top 15 keywords in the co-occurrence of keywords analysis

Rank	Keyword	Occurrences	Total link strength
1.	physical education	631	5126
2.	primary school	425	4487
3.	humans	420	5268
4.	children	385	4536
5.	article	330	4320
6.	female	330	4408
7.	male	327	4373
8.	PA	305	3316
9.	schools	276	3524
10.	controlled study	197	2787
11.	human experiment	187	2518
12	physical education and training	187	2687
13.	exercise	174	2416
14.	students	150	1866
15.	major clinical study	139	1955

Discussion

Findings from the bibliographic coupling analysis have synthesised research streams on future trends. This bibliographic result provides significant information about emerging and future trends related to the importance of PE in enhancing PA, motor skills, and student well-being through the TgfU approach. This aligns with the study by Arufe-Giráldez et al. (2023), which states that PE teaching by teachers is expected to have positive effects on students' psychological, motor, affective-emotional, and social domain.

Table 4. Co-word analysis on GCAs

Cluster No and colour	Cluster label	Number of keywords	Representative Keywords
1 (Red)	"Enhancing student development through comprehensive physical education programs in primary schools".	22	Physical education, primary school, education, curriculum, teaching, learning, motivation, skills
2 (Green)	"The impact of physical fitness and health promotion on academic achievement and psychological well-being in schools".	13	Schools, physical fitness, academic achievement, health promotion, psychology, physical education and training
3 (Blue)	"The role of PA in developing motor skills and managing obesity in preschool children".	13	PA, preschool childrens, male, female, body mass, obesity, motor skill

As revealed in each formed cluster, Cluster 1 emphasises the importance of PE in increasing PA and supporting children's health development by increasing MVPA and reducing inactive time. Next, Cluster 2 focuses on learning strategies to improve students' PA and fitness, including the integration of multi-teaching styles and integrative approaches. Additionally, Cluster 3 highlights the importance of the teacher's role in providing inclusive and student-centred PE. Cluster 4 explores the MBP approach in PE, which can enhance MVPA, motivation, and students' physical engagement. Finally, Cluster 5 highlights the use of TGfU to improve metacognitive behaviour and social constructivism in primary schools.

These findings provide clear direction regarding current research trends that point towards the utilisation of TGfU in PE teaching in primary schools. The use of TGfU, which employs a game-based approach, has been proven to improve physical self-perception, intrinsic motivation, well-being, physiological, and potential psychological outcomes for children (Yan et al., 2023). In addition, the approach is believed to enhance outcomes in tactical skills, skill execution, affective, procedural knowledge, and/or PA, thereby improving health and technical approaches (Breed et al., 2024). The integration of TGfU supports PA enjoyment and specific self-beliefs and quality of life perceptions that contribute to children's subjective well-being (Papadopoulos et al., 2022). For this reason, it is recommended that researchers promote new models or approaches that are easier to apply than the TGfU model (Arufe-Giráldez et al., 2023). Regarding the planning of learning programmes associated with PA, several factors must be considered, including the role of teachers, the environment, and motor skill development and competence (Coe, 2018).

Future trends identified in the co-word occurrence analysis should consider that the PE curriculum should integrate physical, cognitive, social, and emotional development, taking into account curriculum flexibility, addressing local needs, and focusing on individual students (Cluster 1). A comprehensive curriculum can enhance physical fitness, health promotion, academic achievement, and psychological well-being in schools, developing motor skills and managing obesity (Clusters 2 and 3). The planning of the PE curriculum is designed holistically through a school-based multi-component approach. Interventions to increase PA in schools have been shown to reduce anxiety, increase resilience, improve well-being, and promote positive mental health in children and adolescents (Andermo et al., 2020) and effectively enhance a variety of motivational outcomes (Kelso et al., 2020). PE is considered important for fostering lifelong attitudes towards PA, where engagement, enjoyment, and lasting commitment to PA are influenced by perceived competence and relatedness. However, these needs can be hindered by significant variations in maturity levels (Towlson et al., 2024).

Pedagogical interventions with a game-based approach like TGfU can be used to foster healthier students, both physically and psychologically, and support better academic outcomes. Continued research is needed to understand and validate the application of the TGfU instructional model in the PE curriculum (Hodges-Kulinna et al., 2024). Additionally, future trends related to motivational interventions highlight girls as participants with special interest, as well as adopting new methodologies through web-based interventions and implementing active breaks or mental breaks during traditional classroom lessons (Vaquero-Solís et al., 2020).

Conclusions

The bibliometric review has provided important insights for academics and practitioners regarding the knowledge structure related to the implementation of TGfU in primary schools. Based on the bibliographic coupling, several themes relate to the importance of PE in enhancing PA, motor skills, and student well-being through the TGfU approach. At the same time, the co-word analysis presents research streams related to the development of the PE curriculum, emphasising the use of TGfU and the importance of a holistic approach that integrates the physical, cognitive, social, and emotional development of students. The findings from this research will enable the increased application of TGfU in enhancing PA, motor skills, and the well-being of primary school students. Additionally, further research is needed to understand and validate the application of the TGfU instructional model in the PE curriculum.

This study has several limitations related to the review conducted. The qualitative analysis performed by the authors may contain elements of subjectivity in determining the results. Therefore, inter-rater or inter-author reliability is needed to reduce the possibility of subjectivity in qualitative interpretation. Additionally, the analysis was only conducted using the Scopus database. In the future, it is recommended to conduct similar bibliometric analyses using other databases such as Web of Science (WoS) or a combination of Scopus and WoS, following the analysis steps recommended by Lim et al. (2024). The authors also recommend conducting systematic reviews related to the implementation of TGfU in PE teaching in primary schools.

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Conflict of Interest

Authors declare no conflict of interest regarding this paper.

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Виявлення сучасних та перспективних тенденцій щодо впровадження моделі учбового процесу «Навчання за допомогою ігрових елементів для тренування розуміння» в початковій школі: Бібліометричний аналіз

Ірфан Октавіанус[1ABCDE], Урай Густіан[2ABCDE], Андіка Тріанщах[2ABCDE]

[1]Падангський державний університет
[2]Університет Танджунгпура

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

Реферат. Стаття: 11 с., 4 табл., 3 рис., 78 джерел.

Історія питання. На заняттях з фізичного виховання (ФВ) основна увага часто приділяється спортивним навичкам за допомогою командних методів навчання, що може призвести до виникнення в учнів труднощів в контексті розуміння та ефективного проведення ігор. З метою розв'язання цієї проблеми запроваджено методику «Навчання за допомогою ігрових елементів для тренування розуміння» (Teaching Games for Understanding, TGfU) в якості ефективнішого підходу щодо покращення тактичного розуміння та ігрових навичок, а також підвищення залученості учнів до занять із фізичної активності.

Мета дослідження. Мета цього дослідження полягала у визначенні сучасних наукових тенденцій та майбутнього потенціалу впровадження методики TGfU у практику фізичного виховання в початковій школі через проведення бібліометричного аналізу.

Матеріали та методи. Застосовано бібліометричний підхід шляхом аналізу 977 документів з наукометричної бази даних Scopus, опублікованих у період з 2015 по 2024 роки. Аналіз даних проводився із використанням програмного забезпечення VOSviewer для картографування бібліографічних мереж та аналізу ключових слів. З метою визначення нових дослідницьких тенденцій та прогнозування перспектив впровадження моделі учбового процесу «Навчання за допомогою ігрових елементів для тренування розуміння» було застосовано метод наукового картографування.

Результати. За результатами аналізу встановлено, що впровадження методики TGfU сприяє ефективному покращенню фізичної активності, рухових навичок та благополуччю учнів початкових класів. Однак для забезпечення комплексного розуміння та підтвердження зазначених висновків необхідне проведення подальших досліджень. Сучасні тенденції підкреслюють важливість фізичного виховання як чинника підвищення фізичної активності, рухових навичок і благополуччя учнів за допомогою підходу TGfU. Перспективні тенденції вказують на розробку навчальних програм з ФВ, що наголошують на інтегрованому використанні методики TGfU та холістичних підходів.

Висновки. Впровадження моделі учбового процесу TGfU в початковій школі має великий потенціал щодо вдосконалення механізму залучення до занять фізичною культурою, розвитку тактичних навичок та психологічного благополуччя

учнів. До проблемних питань належать оптимізація ролі вчителів як фасилітаторів та адаптація навчальної програми для ширшого застосування TGfU. Слід провести подальші дослідження задля підтвердження застосування методики TGfU у навчальних програмах з фізичного виховання та розробки підходів, що відповідають потребам учнів початкових класів.

Ключові слова: викладання фізичного виховання, навчання за допомогою ігрових елементів для тренування розуміння, початкова школа, перспективні тенденції досліджень.

Information about the authors:

Oktavianus, Irfan: irfanadhe@fik.unp.ac.id; https://orcid.org/0000-0002-8949-8508; Department of Sport Coaching Education, Universitas Negeri Padang, Jl. Prof. Dr. Hamka No.1, Air Tawar Bar., Kec. Padang Utara, Kota Padang, Sumatera Barat 25173, Indonesia.

Gustian, Uray: uray.gustian@fkip.untan.ac.id; https://orcid.org/0000-0001-5117-5861; Department of Sport Coaching Education, Universitas Tanjungpura, Jl. Prof. Dr. H. Hadari Nawawi, Bansir Laut, Kec. Pontianak Tenggara, Kota Pontianak, Kalimantan Barat 78124, Indonesia.

Triansyah, Andika: andika.triansyah@fkip.untan.ac.id; https://orcid.org/0000-0002-9598-9549; Department of Physical Education, Universitas Tanjungpura, Jl. Prof. Dr. H. Hadari Nawawi, Bansir Laut, Kec. Pontianak Tenggara, Kota Pontianak, Kalimantan Barat 78124, Indonesia.

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Review Article

High-Flying Research Trends and Innovations in Young Athletes' Jump Training: A Bibliographic Analysis of Research Over Ten Years

Cahyo Yuwono[1ABCDE], Adi S[1ABCDE], Mahenderan Appukutty[2ABD], Erna Setyowati[1DE], Bondan Fiqi Riyalda[3CDE], Hilmy Aliriad[4BCD] and Made Bang Redy Utama[5BCD]

[1]Universitas Negeri Semarang
[2]Universiti Teknologi MARA
[3]Badan Riset dan Inovasi Nasional (Indonesia)
[4]Universitas Nahdlatul Ulama Sunan Giri
[5]Universitas Negeri Jakarta

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

Corresponding Author: Cahyo Yuwono, e-mail: cahyoyuwono@mail.unnes.ac.id
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Abstract

Objectives. This bibliometric study aimed to track the evolution of research trends related to athletic jumps.

Materials and methods. This study was a systematic review with conducting a bibliometric analysis. Using a thorough approach, articles published since 2014 were found using the keywords "Athletics Jump Training" in research journals indexed in the SCOPUS database. A total of 222 articles were examined. Ten (10) articles were therefore selected for additional investigation using SciVal and the VOSviewer computer programs. For standard operationalization, this study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).

Results. The highest number of articles was published in 2021, the highest citations was recorded in 2019, the greatest number of authors was involved in 2021, and the highest number of readers — in 2015. There were 3 keyword clusters that reflected various research focusing on athletics jump training for younger players. The most frequently occurring keywords in this study were "Athlete", "Muscle Strength", and "Athletic Performance". The United Kingdom (30), Brazil (25), and the United States (17) were the three nations with the highest number of publications on jump training in sports. Factors influencing the development of young jumper athletes and plyometric training for jump performance were the main themes that covered various aspects of the research trend over the last ten years, based on the top ten most cited references in athletics training for younger players.

Conclusions. The study focuses on athletics jump training for younger players, with notable publication peaks in 2021 and citation highs in 2019. Key themes in the most cited references include factors influencing young athletes' development and the role of plyometric training. The United Kingdom, Brazil, and the United States led in publications on this topic. Research on athletics jump for athletes under the age of 18 has grown significantly.

Keywords: athletics, jump, training, bibliographic.

Introduction

Jump training, also known as plyometrics, involves exercises that train muscles to exert maximum force in short intervals of time to increase power, strength, and explosiveness. Young elite long jumpers showed a trend towards improved vertical jump performance and lower perceived fatigue during the competitive phase (Franceschi et al., 2020). Improving technical skills in the long jump relies on a focus on biomechanical indices such as running speed, kinetic energy, and sensory system dominance (Wang et al., 2021). The event emphasizes explosive strength and coordination, with the athlete's natural ability playing a significant role (Tifrea & Costache, 2015). Elite long jumpers exhibit enhanced vertical jump performance and reduced fatigue during competition, with improved technical skills being closely tied to biomechanical factors like running speed and kinetic energy. At the same time, explosive strength, coordination, and inherent athletic ability remain crucial for success in the long jump event.

ТМФВ
ТОВ ОВС

The most common injury in long jumpers was ankle sprains (23.3%), for high jumpers, flexor hallucis longus tendinosis (15.8%) (Enoki et al., 2021). Fast stretching combined exercise can effectively improve lower extremity explosive power in long jump athletes (Liu et al., 2022). Understanding research trends in athletics jump training for young players is essential for optimizing training practices, enhancing athlete development, and adopting evidence-based methods to improve performance and safety.

Bibliometric analysis helps identify important research issues, trends, and gaps in sports, guiding researchers to focus on relevant topics and gaps in the research (Dindorf et al., 2023). Bibliometric analysis helps explore and analyze large volumes of scientific data, shedding light on emerging areas and highlighting the evolutionary nuances of a specific field (Donthu et al., 2021). Bibliometric analysis helps understand the evolution of professional success as a scientific discipline, identifying patterns of convergence and divergence in various topics (Pico-Saltos et al., 2021)

Sport biomechanics research should focus on providing athletes and coaches with feedback based on biomechanical data, bridge the gap between researchers and practitioners, and improve performance analysis and technique improvement (Ae, 2020). The main deficiencies identified in plyometric jump training research are the lack of studies in women, individual sports, and high-level athletes, as well as inadequate descriptions of training prescriptions (Ramirez-Campillo et al., 2020). Various visual regulation strategies and movement adaptability are important in the long jump sprint, which influences the gait regulation towards the take-off board (McCosker et al., 2021)

Based on previous research: focus on squat style long jump assessment only (Kastrena et al., 2020), lack of concern in Indonesian athletic (Daulay et al., 2020), lack of appropriate training methods for optimal long jump performance (Yani, 2015). This study is crucial as it highlights recent trends and advancements in jump training for young athletes over the past decade, providing a comprehensive bibliographic analysis that can inform coaches, trainers, and researchers about evolving methodologies, effectiveness, and gaps in current practices. Its novelty lies in synthesizing a decade's worth of research to offer insights into the most impactful training strategies and emerging trends in the field.

The primary goal of this bibliometric study is to track the evolution of research trends in athletic jump.

1. To examine the patterns in athletic jump training research over the previous ten years.
2. To examine the nations that have contributed to the last ten years' research trends in athletic jump training.
3. To examine the pattern of keyword clusters in the last ten years' research trends related to athletic jump training.
4. To evaluate the last ten years' top ten cited papers in the field of athletic training research trends.

Materials and Methods

Materials for Analysis

A total of two hundred and twenty two (222) articles were collected from Scopus. As a result, 139 articles were chosen for additional examination utilizing scival and VOS server software. For this systematic review, the top ten articles that received the most citations were chosen.

Data Source

A bibliometric analysis and systematic review is what this kind of study is called. A thorough approach was used to scan SCOPUS research journal databases for articles. The term "Athletics Jump Training" is utilized. Additionally, articles published within the previous ten years starting in 2024 were excluded from consideration.

Software

The software used in this research is scival and VOS-viewer. The ensuing subchapters detail each software's purpose and applications:

Scival

Finding high-quality research results in literature reviews requires careful sorting of the articles. On publisher websites, researchers have the option of manually sorting articles or using software. SciVal is an analytical tool used to evaluate and visualize research data and academic publications. Developed by Elsevier, the tool allows users, such as educational institutions and researchers, to gain insights into research performance, collaborations, and trends across a range of disciplines.

Vos Viewer

In research, novelty is an absolute necessity. A program called VOSviewer is used to map network-based research and visualize research mapping. Researchers frequently use this software to identify gaps in the research topic that needs to be explored. When gaps in the research topic are identified, there is a chance that the conducted research will be novel.

Procedure

As indicated in Figure 1, this study's standard operationalization adheres to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).

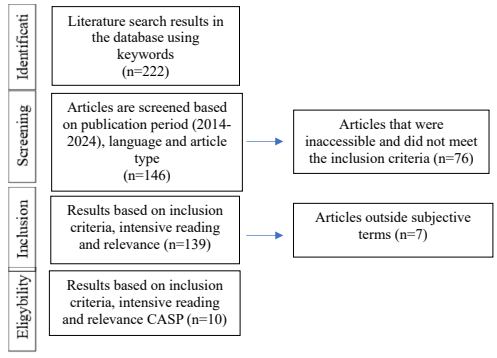

Fig. 1. PRISMA flowchart of the article selection process

Results

Research trend of jump training for young player. Table 1 displays the study trends on jump training for young players in this evaluation of the literature. There are significant annual fluctuations in the number of publications (f). On the other hand, the total citation count, or Total Cited, tends to rise over time.

Table 1. Jump training research conducted in young athletes from 2014 to 2024

Year	f	Total Cited	Author	Views
2014	10	208	53	444
2015	9	302	47	641
2016	12	212	53	491
2017	7	217	31	309
2018	6	113	38	290
2019	18	305	77	614
2020	10	42	48	272
2021	23	118	113	522
2022	18	84	99	465
2023	22	49	91	384
2024	10	4	45	109
Total	145	1654	695	4541

Table 2. Top 10 countries contributed to jump trainning research trend over 10 years for young athlete

Country	f	Total Cited	Views Count
United Kingdom	30	352	751
Brazil	25	268	481
United States	17	388	636
Spain	14	130	201
China	13	11	280
Rusia	12	26	374
Greece	11	233	327
Australia	11	269	397
Germany	10	133	528
Poland	9	39	189
Portugal	8	23	117
Total	93	1179	

Discussion

Various biomechanical and physiological factors, including take-off mechanics, flexibility, and the type of obstacles encountered, influence the jumping technique. The take-off phase significantly impacts the flight phase when jumping. Faster leg placement on the support correlates with an increased initial velocity and reduced flight time.

Table 3. Top 10 cited publications in jump trainning research for young athlete

Author/Total Cite	Methods	Result
Tønnessen et al., 2015 / 89	Mixed models	Usually the primary consider to display supreme and relative yearly execution improvements in running and hopping occasions for competitive competitors from early to late youth.
Loturco et al., 2018 / 73	Experiment	These discoveries strengthen the mechanical concepts supporting the force-vector hypothesis, and give coaches and wear researchers with important data almost the potential utilize and benefits of utilizing vertically- or horizontally-based preparing works out.
Bogdanis et al., 2014 / 56	Experiment	Isometric were more successful than CON and ECC muscle activities in expanding dangerous leg execution when the motivation of the ground response drive of the conditioning work out was compared
Chelly et al., 2015 / 49	Experiment	Including plyometric preparing moved forward imperative components of athletic execution relative to standard in-season preparing in youthful competitor
Loturco et al., 2019 / 48	Experiment	Quicker competitors performed way better in strength-power tests, in both stacked and emptied conditions, as affirmed by the solid relationships watched between speed and control measures.
Veliz et al., 2014 / 48	Experiment	Particular quality and high-intensity preparing in male WP players for 18 weeks delivered a positive impact on execution qualities exceedingly particular to WP.
Zaras et al., 2014 / 47	Experiment	Execution increments essentially after decreasing with LT or HT in track and field hurlers, but HT leads to greater increases in quality, entirety body control, and RFD.
Giroux et al., 2016 / 46	Experiment	Differences between measured and optimal force-velocity profiles raise potential sources of performance improvement in elite athletes.
Fischetti et al., 2018 / 41	Experiment	Eight weeks of plyometric training added to the standard program of athletics was highly likely to improve the lower limbs speed and explosive strength in young athletes
McCosker et al., 2019 / 31	Experiment	Jump should not be viewed as a behaviour in isolation, but rather as part of a complex system of connected performance events which contribute to achievement of competitive outcomes.

Fig. 2. Jump trainning research trend over 10 years for young athlete

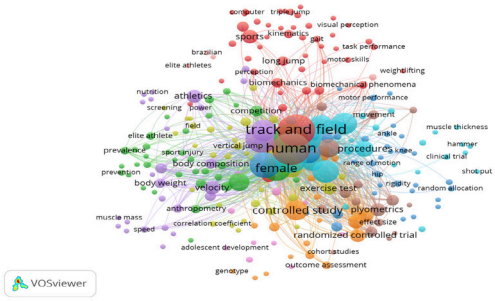

Fig. 3. Keyword cluster pattern in jump trainning research for young athlete

At the same time, a greater take-off angle enhances the total centre of mass velocity during flight (Rozhkov et al., 2022). Flexibility training, such as static stretching, can alter movement techniques during jumps. Although it increases ground contact time and joint flexion, it does not necessarily enhance performance outcomes (Zhang et al., 2020). In equine jumping, the type of obstacle affects jumping technique, with poor jumpers showing lower hindlimb acceleration at take-off. This highlights the importance of adapting jumping techniques based on external conditions (Barrey & Galloux, 2010).

Plyometric training provides superior benefits than strength training for improving vertical jump, linear sprint, and change of direction performance (Pardos-Mainer et al., 2021). Strength training with complementary dynamic whole body electromyostimulation and plyometric exercises improves maximal strength and jumping performance (Rappelt et al., 2023). Plyometric jump training can increase muscle activation during strength and jumping tasks, with a significant positive relationship between changes in muscle activation and changes in jumping performance (Ramirez-Campillo et al., 2021).

Young elite long jumpers show an increasing trend in vertical jump performance and possibly lower perceived fatigue during the competitive phase (Franceschi et al., 2020). Long jumpers have special muscular capabilities in their take-off muscles, with greater hip extensor torque and active contraction of the knee flexor group being important to avoid damage to the posterior femoral muscle group (Ren et al., 2022). Long jumpers need muscle strength training to develop isokinetic muscle strength, which can effectively prevent injury to lower extremity joint motion (Yang et al., 2022). Fast stretching combined exercise can effectively improve lower extremity explosive power in long jump athletes (Liu et al., 2022). Characteristics of long jump athletes include a focus on biomechanical indices such as running speed, kinetic energy, and sensory system dominance, with visual being the primary system in 42.42 % of athletes (Wang et al., 2021). Weighted squats can increase lower-limb explosive power in long jumpers, resulting in better athletic results (Zong, 2022). The front somersault technique, which involves a frontal flexion movement, has been proposed to allow for greater horizontal distance in the long jump due to reduced drag and increased angular momentum at takeoff (Williams, 2023).

High jumpers can improve their leg support strength by applying isokinetic knee joint strength training (Li et al., 2022). High jumpers exhibit lower fascicle shortening velocities and higher tendon velocities, indicating more efficient neuromuscular control (Jo & Lee, 2023). The main deficiencies identified in plyometric jump training research are the lack of studies in women, individual sports, and high-level athletes, as well as inadequate descriptions of training prescriptions (Ramirez-Campillo et al., 2021). Strengthening psychological training in athletes, along with regular physical training, is an important factor in increasing competition effectiveness (Cheng, 2023). The curved approach to the high jump results in a greater center of mass height without increasing joint kinetic forces during takeoff (Sado et al., 2021).

Triple jump athletes require high physical qualities such as muscular strength, explosive power, and coordination capacity, as well as a training plan that enhances adaptability and self-protection abilities (Cao & Wang, 2023). Three-step jumpers have a wider take-off range and a longer take-off time, with a 25 cm platform depth jump exercise that achieves the best take-off effect (Ma, 2021). Highly skilled triple jumpers reduce the duration of the flight period in the final step, increase the takeoff speed, and use different options for combining takeoff and takeoff (Konestyapin et al., 2022).

Conclusions

The research focuses on athletics jump training for younger players, with notable publication peaks in 2021 and citation highs in 2019. Key themes in the top-cited references include factors influencing young athletes' development and the role of plyometric training. Western countries such as the United Kingdom, Brazil, and the United States led in publications on this topic. The current studies should focus on Functional Movement Screening (FMS), whereby, in recent years, screening tools like FMS have been used to assess baseline movement patterns and identify potential injury risks before implementing jump training. Another point to look into is the age-specific periodization training. Tailored jump training programs based on the developmental stages of young athletes have gained importance. Lastly, the emphasis is on the gradual increase in intensity, focusing on biomechanics and injury prevention. Jump training may reduce injury risks, such as anterior crucial ligament (ACL) tears, through exercises that promote better landing mechanics, strength in supporting muscles (quads, hamstrings, hips), and balance.

Future research should focus on longitudinal studies to assess the long-term impacts of recent training innovations on performance and injury prevention. Comparative analy-

ses of various training methods could reveal the most effective approaches, while biomechanical studies could explore how specific techniques affect outcomes. Integrating new technologies, such as wearable sensors and virtual reality, may enhance training and performance monitoring. Additionally, investigating psychological factors, customizing training programs, and developing injury prevention strategies are crucial. Exploring cross-sport training comparisons, cultural and regional differences, and the relationship between training load and recovery can further refine and optimize jump training practices for young athletes. Personalized or individually tailored training is the key to better sporting performance among youth, and this impact can be maintained throughout adulthood.

Conflict of Interest

Authors declare no conflict of interest regarding this paper.

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Провідні наукові тенденції та інновації щодо стрибкових тренувань юних спортсменів: Бібліографічний аналіз досліджень за десять років

Кахьо Ювоно[1ABCDE], Аді С[1ABCDE], Махендеран Аппукутті[2ABD], Ерна Сетьоваті[1BDE], Бондан Фікі Ріялда[3CDE], Хілмі Аліріад[4BCD], Маде Банг Реді Утама[5BCD]

[1]Семарангський державний університет
[2]Технологічний університет МАРА
[3]Національне агентство досліджень та інновацій (Індонезія)
[4]Університет Нахдлатул Улама імені Сунана Гірі
[5]Джакартський державний університет

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

Реферат. Стаття: 7 с., 3 табл., 3 рис., 40 джерел.

Мета дослідження. Це бібліометричне дослідження мало на меті відстежити еволюцію дослідницьких тенденцій, пов'язаних із тематикою легкоатлетичних стрибків.

Матеріали та методи. Дослідження представляло собою систематичний огляд із проведенням бібліометричного аналізу. Застосовуючи ґрунтовний підхід до проведення дослідження, у журналах, індексованих в наукометричній базі даних SCOPUS знайдено статті, опубліковані з 2014 року за ключовими словами "Athletics Jump Training" («Тренування стрибків у легкій атлетиці»). Загалом було досліджено 222 статті. У результаті було відібрано десять (10) статей з метою додаткового вивчення за допомогою комп'ютерних програм SciVal та VOSviewer. Щодо стандартної операціоналізації, це дослідження відповідало стандартам «Переважних елементів звітування для систематичних оглядів і мета-аналізів» (PRISMA).

Результати. Найвищий показник кількості опублікованих статей спостерігався у 2021 році, найвищий показник цитованості зафіксовано у 2019 році, найбільша кількість авторів була залучена у 2021 році, а максимальна кількість читачів – у 2015 році. Виявлено 3 кластери ключових слів, що відображають численні дослідження, зосереджені на вивченні легкоатлетичних тренувань стрибків юних спортсменів. Найпоширенішими ключовими словами в рамках зазначених досліджень були «Спортсмен», «М'язова сила» та « Спортивна результативність». Велика Британія (30), Бразилія (25) і Сполучені Штати (17) склали трійку країн з найбільшою кількістю публікацій щодо стрибкових тренувань у спорті. Фактори, що впливають на розвиток юних спортсменів-стрибунів та пліометричні тренування, спрямовані на підвищення результативності виконання стрибків, були головними темами, які охоплювали різні аспекти дослідницької тенденції за останні десять років, ґрунтуючись на десяти найбільш цитованих джерелах у галузі легкоатлетичної підготовки юних спортсменів.

Висновки. Дослідження фокусується на вивченні легкоатлетичних стрибкових тренувань юних спортсменів, зокрема значний рівень кількості публікацій спостерігався у 2021 році, а максимальний показник цитованості – у 2019 році. До ключових тематик найбільш цитованих публікацій належать фактори, що впливають на розвиток юних спортсменів, а також роль пліометричних тренувань. Лідерами за кількістю публікацій на зазначену тематику були Велика Британія, Бразилія та США. Відзначено суттєвий ріст кількості досліджень щодо вивчення легкоатлетичних стрибків спортсменів вікової категорії до 18 років.

Ключові слова: легка атлетика, стрибок, тренування, бібліографічний.

Information about the authors:

Yuwono, Cahyo: cahyoyuwono@mail.unnes.ac.id; https://orcid.org/0000-0003-3169-022X; Physical Education Department, Universitas Negeri Semarang, Sekaran, Kec. Gn. Pati, Kota Semarang, Jawa Tengah 50229, Indonesia.

Adi S: adis@mail.unnes.ac.id; https://orcid.org/0000-0001-8450-2005; Physical Education Department, Universitas Negeri Semarang, Sekaran, Kec. Gn. Pati, Kota Semarang, Jawa Tengah 50229, Indonesia.

Appukutty, Mahenderan: mahen@uitm.edu.my; https://orcid.org/0000-0001-8114-5575; Faculty of Sports Science and Recreation, Universiti Teknologi MARA, Jalan Ilmu 1/1, 40450 Shah Alam, Selangor, Malaysia.

Setyowati, Erna: ernasetyowati@mail.unnes.ac.id; https://orcid.org/0009-0001-1842-7091; Faculty of Engineering, Universitas Negeri Semarang, Sekaran, Kec. Gn. Pati, Kota Semarang, Jawa Tengah 50229, Indonesia.

Riyalda, Bondan Fiqi: bond003@brin.go.id; https://orcid.org/0000-0002-9816-2723; Directorate of Laboratory Management, Research Facilities and Science and Technology Areas, National Research and Innovation Agency (Indonesia), Gedung B.J. Habibie, Jl. M.H. Thamrin No. 8, Jakarta Pusat 10340, Indonesia.

Aliriad, Hilmy: hilmy@unugiri.ac.id; https://orcid.org/0000-0002-7287-6429; Physical Education Department, Universitas Nahdlatul Ulama Sunan Giri, Jl. Ahmad Yani No. 10, Bojonegoro, Jawa Timur 62115, Indonesia.

Utama, Made Bang Redy: made.bang@unj.ac.id; https://orcid.org/0000-0001-7553-5892; Sport Coaching Department, Universitas Negeri Jakarta, Jl. Rawamangun Muka No.11, RT.11/RW.14, Rawamangun, Kec. Pulo Gadung, Kota Jakarta Timur, Daerah Khusus Ibukota Jakarta 13220, Indonesia.

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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.

Редакція журналу
«Теорія та методика фізичного виховання»

Етапи редакційного процесу

Попередній розгляд подання (до 2 тижнів)

- призначення редактора;
- перевірка рукопису щодо відповідності тематики журналу;
- технічна перевірка (обсяг рукопису, обсяг анотації, оцінка подання щодо стилістичних та бібліографічних вимог, викладених у Керівництві для авторів);
- визначення актуальності, новизни та оригінальності роботи;
- наявність педагогічного експерименту, його відповідність методології дослідження, яку можна повторити (репрезентативність вибірки, однорідність вибірки за віком, руховою підготовленістю, рівнем спортивної підготовленості, стажем занять, тощо);
- якщо рукопис є оглядовим, то перевіряється використання протоколу PRISMA, який охоплює систематичні огляди та мета-аналізи. Авторам рекомендовано заповнити контрольний список і блок-схему та включити їх до подання.
- перевірка на плагіат.

Якщо рукопис отримав позитивну оцінку, то він спрямовується на рецензування, інакше – відхиляється.

Рецензування

Підбір та запрошення рецензентів, очікування відповіді на запит (до 2 тижнів). Типовий період, необхідний для проведення рецензування складає чотири тижні.

Всі статті, що оприлюднюються в журналі, проходять рецензування.

Головний редактор журналу направляє статтю на рецензування фахівцям, що мають найбільш близьку до теми статті наукову спеціалізацію. Рецензування проходить за подвійною сліпою схемою.

У кожній статті в процесі рецензування завжди розглядаються:

- етичні аспекти;
- оригінальність твору;
- важливість інформації;
- чіткість та зрозумілість тексту;
- доцільність використання методів дослідження;
- інтерпретація результатів;
- обґрунтованість висновків.

Прийняти рішення щодо публікації (до 2 тижнів)

- обговорення рецензій: запит нової версії, прийняття або відхилення подання;
- якщо приймається рішення про запит виправленої версії рукопису, то автору надається 2 тижні на підготовку рукопису;
- якщо приймається рішення про прийняття рукопису, то він спрямовується на етап підготовки до публікації.
- якщо приймається рішення про прийняття рукопису, то авторам буде необхідно перерахувати журналу Плату за публікацію статті для компенсування витрат на видання.

Підготовка до публікації (4 тижні)

- літературне редагування;
- комп'ютерна верстка;
- ознайомлення авторів з макетом;
- виправлення помилок друку та форматування;
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