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CONTENT/ SOMMAIRE/ INHALT/ CUPRINS

STUDIA UBB EDUCATIO ARTIS GYMN., LXX, Special Issue 2, 2025, pp. 9-18
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RATIONALIZATION OF MEANS FOR DEVELOPING ABDOMINAL MUSCLE STRENGTH THROUGH THE SIT-UP TEST IN THE EDUCATIONAL PROCESS FOR STUDENTS AGED 6 TO 10 YEARS

Carla Silvia BĂLOI[1*], Tiberiu Silviu PUTA[1], Silvia POPESCU[1], Csilla GRĂDINARU[1]

ABSTRACT. ***Introduction***: There are various strategies aimed at strengthening the abdominal muscles, focusing on increasing their thickness to enhance trunk stability and posture. The exercises must engage all abdominal muscles across different planes of movement and may include two types of contractions: isometric and concentric. ***Objective***: The present study aims to rationalize specific means to optimize the development of abdominal muscle strength within the instructional process for students aged 6 to 10 years. ***Materials and Methods***: In this stage of the study, the subjects were tested to assess the development of abdominal muscle strength. The test battery applied included the *Sit-Up Test* to evaluate abdominal strength. ***Results***: Following the administration of the *Sit-Up Test* to second-grade students, group IIF showed a significant improvement in physical performance ($p = 0.022$), while the other groups (IF, IB, IIB, IIIF, IIIB, IVF, IVB) did not present significant differences. ***Discussion***: The comparative analysis of the data highlights specific characteristics of abdominal strength development, confirming previous research findings and indicating the need for adapted training programs. ***Conclusions:*** A well-structured physical exercise program can significantly influence the development of abdominal muscles in students, provided that it is adapted to their individual needs and capacities. The methods used must be tailored to each student's strength level. This approach contributes substantially to the improvement of overall performance, both physically and cognitively.

Keywords: Psychomotricity, students, girls, boys, Si-up Test

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INTRODUCTION

It is essential to precisely understand the effects of strength training over specific periods to effectively improve muscular strength. Equally important is the ability to measure muscular strength with ease, although some body regions allow for simpler assessments than others. Muscular strength is generally classified into static strength, measured by maximal force, and dynamic strength. Determining maximal capacity is crucial for establishing training loads and methods and must be performed accurately. The abdominal muscles play a key role in intra-abdominal pressure, lumbar spine stabilization, posture maintenance, and trunk movements (flexion, torsion, lateral flexion), making them essential for both athletes and the general population (Noguchi et al., 2013).

An individual's motor abilities are represented by genetically determined motor skills, which constitute the genotypic component (innate motor skills). Acquired motor abilities developed through learning correspond to the phenotypic component (acquired motor skills) of the individual (Neagu, 2012).

Anders et al. (2020) emphasize the importance of training to strengthen the abdominal muscles, which, although significantly less developed than the back muscles, play a crucial role in trunk stability. Their performance can be assessed through muscular endurance and maximal strength. Due to the predominance of type II fibers in the abdominal region, resistance training is essential. However, there is ongoing debate regarding the most effective training methods and their influence on maximal strength.

Alavi et al. (2023) found that there are strategies for strengthening the abdominal muscles that focus on increasing their thickness to improve trunk stability and posture. Exercises should activate all abdominal muscles across different planes of movement and may include two types of contractions: isometric and concentric.

STUDY OBJECTIVES

1. General Objective

The general objective of this study is to rationalize specific means to optimize the development of abdominal muscle strength within the instructional process for students aged 6 to 10 years.

2. Specific Objectives

The specific objectives pursued in the present study are:

- To analyze current methodologies for assessing the development of abdominal muscle strength;
- To implement a program of specific means aimed at optimizing abdominal strength.

MATERIALS AND METHODS

In this stage of the study, the subjects were tested to assess the development of abdominal muscle strength. The test battery applied included: a) **Sit-Up Test** – to evaluate abdominal strength.

a) Sit-Up Test – for the development of abdominal muscle strength

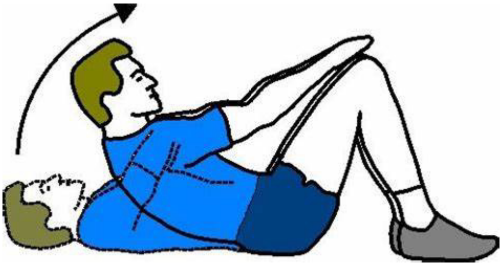


Fig. 1 - Testing of Abdominal Muscle Strength, Eurofit, C.O.E. (1993).
The sit-up test is used to assess the development of the abdominal and hip flexor muscles.

RESULTS

In this study, we assessed the performance of students in grades I–IV on the SIT-UP test to determine the development of abdominal strength. The purpose of this analysis was to investigate whether significant differences exist between the performances of girls and boys on these tests, using non-parametric testing methods, namely the Wilcoxon and Mann–Whitney tests.

Results Obtained for Grade I – Girls and Boys

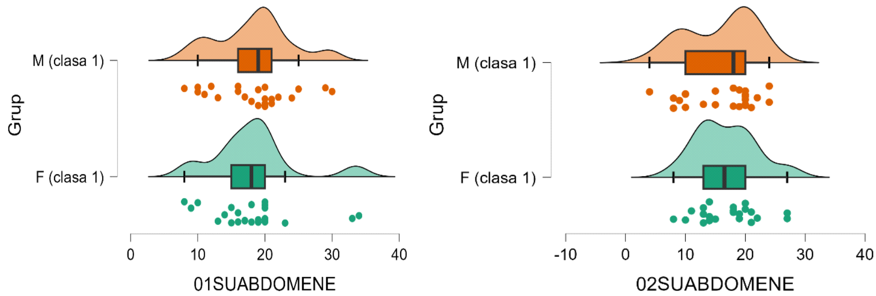
The results were analyzed and compared for both groups (girls and boys), and the findings are presented below.

CHARACTERISTIC	CLASA 1	CLASA 1	CLASA 1	MANN-WHITHEY
	all	F	B	p-value
VARIABILE	mean (standard deviation)	mean (standard deviation)	mean (standard deviation)	
01SUABDOMINALS	17.9 (4.5)	17 (4.3)	19 (4.6)	**0.552**
02SUABDOMINALS	19.6 (3.6)	19.4 (4.1)	19.8 (3)	**0.809**
P-VALUE (WILCOXON)		0.161	0.082	

Notes: SUABDOMINALS – score obtained in abdominal strength tests for Grade I students, (SD) – values are expressed as mean ± standard deviation.

Results Recorded for the SIT UP Variable Measuring Abdominal Muscle Strength (01SUABDOMINALS – 02SUABDOMINALS)

No statistically significant differences were observed in either group with respect to the Mann–Whitney variables (p = 0.552 and p = 0.809) for the tests (01SUABDOMENE and 02SUABDOMENE). The p-values obtained from the Wilcoxon test suggest that the differences for the tested characteristic are not statistically significant, with the significance threshold being non-significant for both girls (p = 0.161) and boys (p = 0.082).



Graph 1. Distribution of the variable SUABDOMENE (SIT-UP) at time points 1 and 2 according to group membership (GE = experimental group, GC = control group).

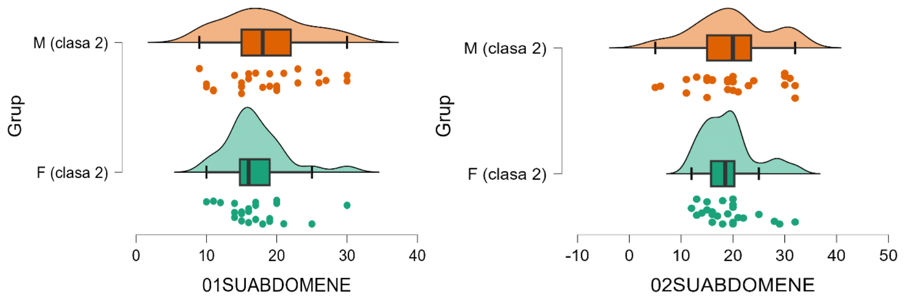
Results Obtained for Grade II – Girls and Boys

CHARACTERISTIC	CLASA 2 all	CLASA 2 F	CLASA 2 B	MANN-WHITHEY
VARIABILE	mean (standard deviation)	mean (standard deviation)	mean (standard deviation)	p-value
01SUABDOMINALS	18.2 (5.7)	17.4 (4.8)	18.9 (6.5)	**0.399**
02SUABDOMINALS	21.5 (6.8)	19.6 (5.7)	23.1 (7.5)	**0.642**
P-VALUE (WILCOXON)		0.022	0.417	

Notes: SUABDOMINALS – score obtained in abdominal strength tests for Grade I students, (SD) – values are expressed as mean ± standard deviation.

Results Recorded for the SIT UP Variable Measuring Abdominal Muscle Strength (01SUABDOMINALS – 02SUABDOMINALS)

In the case of the variables used to determine explosive strength in the abdominal muscles, the results indicate a statistically significant difference between girls and boys ($p < 0.05$), suggesting that girls performed better in this specific test, with a p-value of 0.022 (Wilcoxon). In contrast, for the boys' group, no significant differences were observed between the two groups (p > 0.05), indicating a substantial increase in boys' performance values (p-value = 0.417), except for the Mann-Whitney test, where the performance differences were not statistically significant (p = 0.399 and p = 0.642, respectively).



Graph 2. Distribution of the variable SUABDOMENE (SIT-UP) at time points 1 and 2 according to group membership (GE = experimental group, GC = control group).

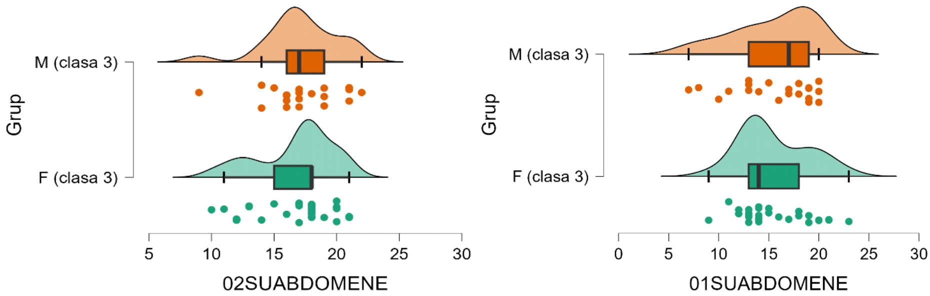
Results Obtained for Grade III – Girls and Boys

CHARACTERISTIC	CLASA 3	CLASA 3	CLASA 3	MANN-WHITHEY
	all	**F**	**B**	
VARIABILE	mean (standard deviation)	mean (standard deviation)	mean (standard deviation)	**p-value**
01SUABDOMINALS	15.6 (3.2)	15.5 (2.5)	15.8 (4.1)	**0.797**
02SUABDOMINALS	18 (1.6)	18.3 (1.4)	17.5 (1.8)	**0.913**
P-VALUE (WILCOXON)		0.386	0.952	

Notes: SUABDOMINALS – score obtained in abdominal strength tests for Grade I students, (SD) – values are expressed as mean ± standard deviation

Results Recorded for the SIT UP Variable Measuring Abdominal Muscle Strength (01SUABDOMINALS – 02SUABDOMINALS)

We can state that there are no statistically significant differences in any of the groups regarding the Mann-Whitney variables (p = 0.797 and p = 0.913) for both the experimental and control groups.



Graph 3. Distribution of the variable SUABDOMENE (SIT-UP) at time points 1 and 2 according to group membership (GE = experimental group, GC = control group).

The p-values obtained from the Wilcoxon test suggest that the differences for the tested characteristic are not statistically significant, with the significance threshold being non-significant for both girls (p = 0.386) and boys (p = 0.952).

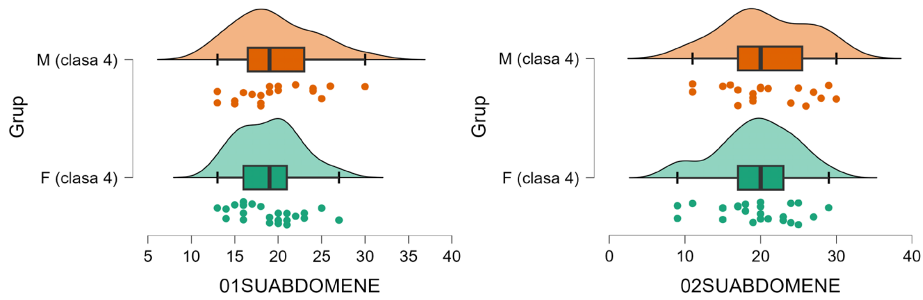
Results Obtained for Grade IV – Girls and Boys

CHARACTERISTIC VARIABILE	CLASA 4 all mean (standard deviation)	CLASA 4 F mean (standard deviation)	CLASA 4 B mean (standard deviation)	MANN-WHITHEY p-value
01SUABDOMINALS	19.2 (4.4)	18 (3.1)	20.6 (5.4)	**0.821**
02SUABDOMINALS	22.5 (4.9)	21.5 (4.7)	23.7 (5.1)	**0.521**
P-VALUE (WILCOXON)		0.428	0.654	

Notes: SUABDOMINALS – score obtained in abdominal strength tests for Grade I students, (SD) – values are expressed as mean ± standard deviation.

Results Recorded for the SIT UP Variable Measuring Abdominal Muscle Strength (01SUABDOMINALS – 02SUABDOMINALS)

The comparative analysis of the results from the latest test indicates that there are no significant differences between girls and boys in terms of their performance on these tests. The p-values are below the significance threshold (0.05) when comparing the Wilcoxon parameters (girls: p = 0.428; boys: p = 0.654) and the Mann–Whitney test (p = 0.821 and p = 0.521, respectively), indicating statistically non-significant differences between genders in the results of the applied tests.



Graph 4. Distribution of the variable SUABDOMENE (SIT-UP) at time points 1 and 2 according to group membership (GE = experimental group, GC = control group).

DISCUSSIONS

Discussion of the results obtained in the Sit-Up Test

In this study, the Sit-Up test results revealed that only first-grade boys demonstrated significant abdominal muscle development compared to other grades.

Psychomotricity, as described by Petrea et al. (2023), is an integrative domain encompassing both motor actions and mental processes, forming a coherent unit. It relies on sensory, perceptual, and cognitive functions, as well as on information reception and processing, significantly influencing individual behavior. Psychomotricity addresses human needs through educational, re-educational, and therapeutic processes and is conceptualized as a unified system based on movement and mental functions. It is influenced by interactions among individuals and the relationship between developmental processes and the educational system, impacting social integration.

According to Ridwan et al. (2023), physical exercise is a planned and repetitive activity aimed at improving or maintaining various physical components. Training objectives include optimizing basic physical quality, developing specific skills, refining techniques and strategies, and enhancing psychological aspects of athletes. Each exercise induces bodily adaptations proportional to the training intensity. Physical exercise is essential for both athletic performance and the physical and mental health of non-athletic individuals.

The study included 24 participants divided into two groups: Group 1 (A1) followed a VO2 max training program, while Group 2 (A2) followed a muscular endurance program. A significant redistribution of performance categories was observed post-intervention: participants classified as “Inadequate” increased from 25% to 50%, whereas those classified as “Weak” decreased from 50% to 25%. No participants were classified as “Good” or “Very Good” in the pre-test.

VO2Max and abdominal muscular endurance were analyzed pre- and post-intervention. Pre-test VO2Max values were p = 0.115 and post-test p = 0.169, both within normal limits. Abdominal muscular endurance pre-test values were p = 0.719. Differences in VO2Max and abdominal endurance were statistically significant post-intervention (p = 0.001), indicating substantial improvements in aerobic capacity and abdominal muscle strength. These results confirm the effectiveness of the applied intervention in enhancing overall physical performance.

Afriyanti et al. (2024) emphasized that abdominal muscle strength is directly influenced by the quality of the muscular system, determined by contraction efficiency, fiber type, and fatigue levels. Abdominal strength refers to a muscle group's ability to generate maximal contraction against resistance. Based on these findings, exercises such as trunk raises and various plank positions are recommended to improve abdominal strength, particularly in the context of Pencak Silat martial arts.

Normative evaluation criteria for the Sit-Up test were established for 10–12-year-old children, differentiated by gender. Boys performing over 23 repetitions and girls over 20 repetitions were classified as "Excellent," while the "Very Poor" category included boys with 0–3 repetitions and girls with 0–1. Intermediate categories ("Good," "Adequate," "Inadequate") were defined according to repetitions, providing an objective framework for assessing performance and gender differences.

Destriana (2024) demonstrated that sit-ups are aerobic exercises that not only strengthen abdominal muscles but also reduce body fat and promote muscle mass development. In a sample of 316 seventh-grade students, most participants scored in the lower performance categories ("Very Low" and "Insufficient"), highlighting the need for targeted physical training.

Saputri (2024) reinforced the importance of fitness testing in sports training, noting that strength, endurance, and power assessments help identify athletes' strengths and weaknesses to guide training programs. Sit-Up evaluations in seventh-grade students revealed strength levels ranging from "Adequate" to "Very Low," attributed to insufficient physical preparation.

The Shapiro-Wilk test indicated a non-normal distribution of Sit-Up results (statistic = 0.911, Sig. = 0.016), confirming significant differences in abdominal strength according to gender and age.

Overall, the comparative analysis highlights significant gender- and age-related differences in Sit-Up performance. These findings underscore the importance of implementing personalized training programs and assessment strategies to improve physical fitness and adapt educational interventions effectively.

CONCLUSION

Abdominal muscle strength development programs for students in grades I–IV can generally be applied across genders, given the similar outcomes observed in most groups.

The SIT-UP test proved to be a reliable tool for assessing abdominal strength, providing objective insights into students' physical development. Nevertheless, its utility may be enhanced when used alongside complementary assessment methods, particularly to capture gender- or age-related variations.

Post-intervention analysis revealed significant differences between girls and boys in the second grade, with girls outperforming boys. This suggests variations in motor development and abdominal strength at this age, highlighting the need to tailor training programs according to gender.

A well-structured exercise program, adapted to individual needs and capabilities, can substantially enhance abdominal muscle development and overall physical and cognitive performance.

In summary, while abdominal strength programs for grades I–IV can be broadly generalized, findings emphasize the importance of gender- and individual-specific adaptations.

Careful program design, aligned with each student's abilities, optimizes physical development, cognitive growth, and overall performance.

STUDY LIMITATIONS

The small sample size and the lack of adequate diversity significantly influenced the representativeness of the results, thereby limiting their general applicability. Furthermore, the focus on primary school students (ages 6–10) reduces the validity of the conclusions for other age groups or educational levels. The results obtained are also dependent on the reliability of the tests used (balance, laterality, spatial orientation, and spatio-temporal orientation), factors that may affect the accuracy of the data.

To validate the conclusions, correlating the findings with similar studies was essential, while analyzing variables such as gender provided an overview of the investigated phenomenon. Long-term observation and the application of the methods during different educational stages contributed significantly to clarifying their effectiveness. Expanding the research to other age groups, including middle school, high school students, and athletes, would allow testing the adaptability of the applied methods. Moreover, the use of advanced technologies, such as modern analytical tools, would enable an improvement in research quality.

AUTHORS CONTRIBUTIONS

Carla Silvia Băloi was instrumental in implementing the intervention plan and conducting the statistical analyses necessary to validate the results, significantly contributing to the formulation of the study's conclusions.
Tiberiu Silviu Puta played a key role in designing and implementing strategies to optimize the investigated component, proposing innovative methods and tools that enhanced psychomotor performance and providing a robust theoretical and practical framework adapted to participants' age and motor development level.

Silvia Popescu and Csilla Grădinaru assisted with manuscript revision, ensuring compliance with academic standards and the journal's editorial requirements.

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THE IMPORTANCE OF NEUROMOTOR TRAINING IN MILITARY PENTATHLON. AN ANALYSIS APPLIED TO THE PREPARATION OF THE CISM OBSTACLE COURSE

Dumitru Cătălin COHAL[1]

ABSTRACT. ***Introduction***: neuromotor training, integrating balance, coordination, agility, and proprioceptive exercises alongside functional training, plays a key role in optimizing performance and preventing injuries in events that involve overcoming fixed obstacles. In military pentathlon, the CISM obstacle course requires an optimal combination of basic motor skills and their effective integration throughout the 20 obstacles. ***Objective:*** this study aimed to evaluate the impact of neuromotor training on obstacle run preparation, focusing on technical performance, movement efficiency, and injury risk reduction. ***Materials and methods***: a 12-week neuromotor training program was implemented during the pre-competition period (march–may) for nationally ranked military athletes. The program included targeted exercises to enhance coordination, balance, agility, and motor control. Performance was assessed through running times, while technical execution and injury incidence were monitored via video and photographic analysis. Equipment used included agility ladders, fit balls, balance boards, small trampolines, plyometric boxes, elastic bands, TRX systems, unstable surfaces (rubber, sand, synthetic turf), smartwatches, and video recording tools. ***Results:*** preliminary analysis showed significant improvements in technical execution, movement economy, and completion times, alongside a reduction in injury frequency among participants. ***Discussion:*** findings indicate that neuromotor training enhances motor control and rapid adaptability in the complex demands of the military obstacle run. Additionally, injury prevention benefits underscore its relevance in military sports preparation. ***Conclusions***: neuromotor training is a valuable complementary method in military pentathlon preparation, improving both performance and physical resilience. Further research with larger samples and varied competitive conditions is needed to validate these results.

Keyword: neuromotor; pentathlon; training; obstacles; military.

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INTRODUCTION

In competitive sports, the neuromotor (or neuromuscular) training method is commonly used. It generally involves combinations of physical exercises with increased mental control that do not necessarily involve sustained physical effort (Chen et al., 2023). The main goal is to improve communication between the brain and muscles to increase confidence, courage, agility, balance, coordination, and muscle strength by forming new synapses in the brain. Proprioception is defined as the body's ability to perceive its position in space and coordinate movements, allowing us to orient and stabilize our body movements without looking at our actions (Qin et al., 2024). It is a trained and developed sense that involves nerve receptors in muscles and tendons that transmit information to the brain, helping to prevent injuries by training balance and reaction speed. Neuromotor training in competitive sports that require overcoming obstacles or maintaining balance over time develops qualities that enable the brain to know exactly what signal to send to the muscles, which in turn can react automatically in situations of imbalance, turning reactions into reflexes, thus increasing the chances of exceptional success while reducing the possibility of injury (Peng et al., 2024). In military pentathlon competitions, the incidence of injuries during training or competitions is high. Starting with 1989, girls actively participate in military pentathlon competitions, thus eliminating gender-based discrimination (Mainenti et al., 2022).

Fig. 1. Aspects from CISM obstacle course training
Sources: the author's personal photo album

The CISM (Council International du Sport Militaries) obstacle course race is part of the military pentathlon competition and is considered the queen of military competitions (Cohal, 2019, pp. 234-239). The competition consists of running a 500-meter course with 20 distinct obstacles. The positioning and complexity of the 20 obstacles, the technique of approaching them, and the ability to maintain a constant running speed give the specificity of the event. The positioning of the obstacles and their difficulty have been designed to optimally test the soldier's speed running qualities and abilities in terms of strength, skill, and endurance, which are also necessary on the battlefield. Through neuromotor training, military athletes develop adequate spatial-temporal abilities, which significantly reduce the risk of injury during obstacle course running. Recent studies show that by increasing the proportion of neuromuscular training in the overall training program, athletic performance increases and, directly proportional to this, courage, self-confidence, and athletic longevity also increase (Akbar, 2022). In the case of the military pentathlon, which is a combined event, the percentages allocated to neuromotor training must take into account the specific multidisciplinary effort and the time allocated for the preparation of the five events. In general, training in the combined military pentathlon event must be customized for the individual athlete and must be optimized taking into account the multidisciplinary training that characterizes them. (Cohal, 2025, pp. 125-133).

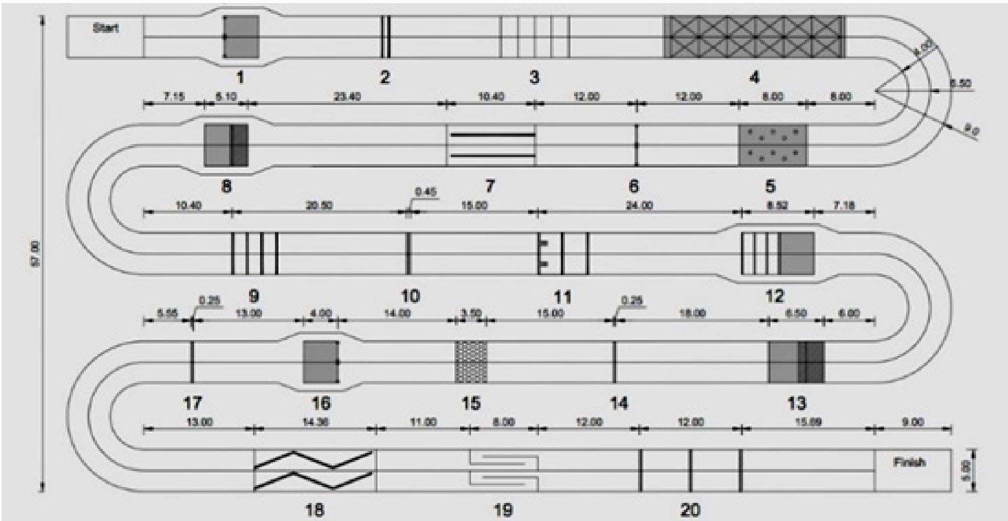

Fig. 2. CISM-type obstacle course diagram

Sources: Military pentathlon competition regulations on https://www.military-pentathlon.info/cms/military-pentathlon/regulations.html p. 32

The fundamental objective of this research is to investigate and compare the effects of neuromotor training on athletic performance in the CISM obstacle course. The study aims to determine the extent to which the integration of this method into the main training plan contributes to reducing the risk of injury, as well as to developing self-confidence and courage, considered direct results of exercises designed to improve agility, balance, coordination, and neuromuscular control.

The analysis of the technique of approaching obstacles during running, as well as how the athlete perceives the intensity of the effort during the test, was the starting point for implementing the neuromuscular training method. The research is based on the premise that performance in military-style obstacle course running is significantly influenced by factors such as proprioception, motivation, courage, and individual effort capacity, alongside the tactical and technical components of competition training (Cohal., 2025).

Therefore, the study aims to provide an applied perspective on the impact of the neuromuscular training method on the physical and psychological behavior of military athletes, while also contributing to the optimization of training strategies in CISM-type events.

Research hypothesis

Regular neuromuscular exercises performed under the direct supervision of specialists improve obstacle-clearing technique over time, leading to better effort and orientation capacity and reducing the incidence of accidents among military pentathletes in the obstacle course event.

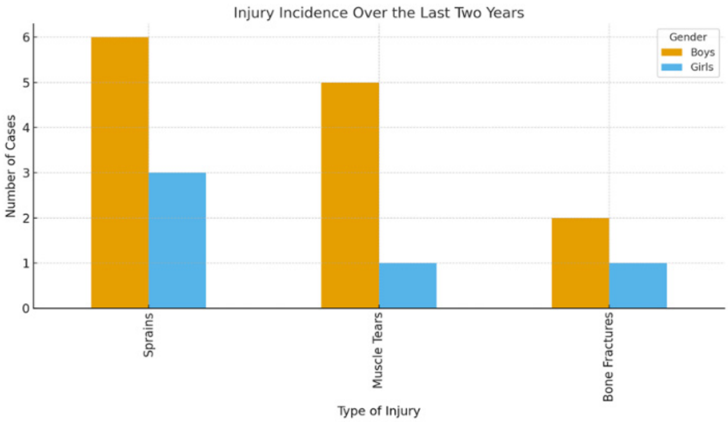

Fig. 3. Graphical interpretation of the incidence of injuries on the CISM-type obstacle course between 2023 and 2024 of athletes from the military pentathlon team.

MATERIAL AND METHODS

In our approach, we used the following research methods: study of specialized literature, observation method, testing and evaluation method, statistical-mathematical and graphical interpretation method.

Study of specialized literature: a structured review of specialized literature was conducted to establish the theoretical framework of the research. Scientific sources indexed in international databases were analyzed, focusing on neuromotor training, integrative neuromuscular training, motor control, agility development, and injury prevention in military and performance sports. The review supported the design and methodological structuring of the 12-week intervention program.

Observation method: systematic direct and video-assisted observation was applied throughout the intervention period. Technical execution during obstacle course simulations was monitored, emphasizing movement coordination, balance control, transition efficiency, and landing mechanics. Video analysis enabled objective identification of technical adaptations and motor pattern optimization.

Testing and evaluation method: performance assessment was conducted through pre- and post-intervention testing under standardized conditions. Obstacle course completion times were recorded using electronic timing devices. Technical execution was evaluated using structured criteria based on biomechanical parameters. Injury incidence was monitored to assess the preventive effects of the training program.

Statistical-mathematical and graphical methods: descriptive statistical indicators (mean, standard deviation, percentage progress) were calculated to quantify performance changes. Comparative analysis between initial and final testing was performed to determine the magnitude of improvement. Graphical representations were used to illustrate performance evolution and injury trends.

The equipment used included agility ladders, fitness balls, balance boards, small trampolines, beams, gymnastics boxes and vaulting horses, plyometric boxes, elastic bands, TRX systems, unstable surfaces (rubber, sand, synthetic turf), Swing Stick flexible bar, smart watches, and video recording devices (Wan, 2025).

Research stages

To achieve the proposed objective, the following research stages were established:

A. Establishing the research sample: 12 military athletes from the extended military pentathlon team in the pre-competition period. Of these, 6 athletes performed specific neuromuscular training (experimental group - Group A) and

6 of them continued their classic training but did not use neuromuscular exercises (control group - Group B). The group homogeneity expressed through the calculation of the standard deviation (SD) is appropriate for conducting the experiment. The average age of the test participants is 23.56 years, with 24.5 years for females and 22.62 years for males. All test participants were informed in advance that the research results would be part of academic research. They took part voluntarily, and the military institution approved the conduct of the study. They also gave their written consent to participate in the research.

B. Development of a neuromotor training plan: the neuromuscular training program included specific exercises to improve coordination, balance, agility, and motor control and was based on a preliminary analysis of the following factors:

- Development of movement coordination skills.
- Increased adaptability.
- Ability to maintain running pace between obstacles.
- Ability to apply obstacle-approach techniques during intense physical effort.

The program was implemented during the pre-competition period between March and May 2025. Until then, the athletes' training plan did not include neuromuscular exercises. The military athletes from the extended national team who participated in the tests have between two and five years of competitive experience as pentathletes. Of these, four are girls and eight are boys, and following the final evaluations, eight were selected, five boys and three girls, to form the representative national team of the army.

The final performance was evaluated by recording the final results of the obstacle course test. Technical execution and injury incidence were monitored through video and photographic analysis. The neuromuscular training program was implemented for athletes in Group A, which was formed based on their results in the initial obstacle course test. Thus, the first six times were combined with the last six, forming two homogeneous groups in terms of results. Neuromuscular training took place in the gym four times a week for 60 minutes, regardless of gender and age. It was individualized and considered all the didactic and pedagogical factors in the training of a combined event such as the military pentathlon.

C. Setting research tasks:

– Evaluating the objectives pursued.
– Analyzing video and photo sequences.
– Data analysis.

Table 1. Initial testing of CISM-type obstacle course running

Group	Time/Sex	Standard Deviation (SD)
A Experimental Group	2’44’’♂ 2’49’’ ♂ 2’51’’♂ 2’56” ♀ 2’59” ♂ 3’10” ♀	**9.11 sec** (≈ ± 0’09’’)
B Control Group	2’47” ♂ 2’50” ♂ 2’54” ♀ 2’57” ♂ 3’01” ♂ 3’13” ♀	**9.27 sec** (≈ ± 0’09’’)

Legend: ♂ symbol for male sex, ♀ symbol for female sex

RESULTS

During the 12 weeks of testing, athletes in group A did not suffer any injuries during training on the obstacle course. In contrast, in group B, there were several minor contusions to the lower limbs, and one athlete suffered a broken finger while crossing obstacle number 11.

At the end of the testing period, the athletes in the experimental group showed a higher level of motivation and greater capacity for effort compared to those in the control group. Analysis of the technique used to approach the obstacles revealed a significant improvement in group A, which was confirmed by analysis of the photo and video sequences taken during the experiment.

Furthermore, the overall approach to running showed notable progress for athletes in group A, with final test results indicating significant improvements in both the female and male categories. Intermediate times showed a progressive increase in the exercise capacity of athletes in group A compared to those in group B.

In particular, the application of the neuromuscular training method to the female participants had a significant impact on the development of self-confidence and courage, which was reflected in their obstacle-crossing technique and in the times recorded both during training and in the final test. The athletes in group A recorded an improvement in timed performance of over 9.8% compared to the initial test results, which is above the overall average obtained of 7.67% (Henry, 2001).

Table 2. Final CISM-type obstacle course running test

Group	Time/Sex						Average Times
A Experimental Group	Performence time/ Percentage increase						Average ∑-sec./ %
	2’ 33” ♂	**2’37” ♂**	**2’38”♂**	**2’41” ♀**	**2’50” ♂**	**2’49” ♀**	2’41”
	11”/6.7%	12”/7.1%	13”/7.6%	15”/8.5*	9”/5.03%	21”/11.1%*	∑-14"/7.67%
B	**2’40” ♂**	**2’44” ♂**	**2’49” ♀**	**2’52” ♂**	**2’57” ♂**	**3’03” ♀**	2’47”
Control Group	7”/4.2%	6”/3.5%	5”/2.9%	5”/2.8%	4”/2.2%	10”/5.2%	∑-6’/3.46%

Legend: ♂ symbol for male sex, ♀ symbol for female sex, ∑ symbol for arithmetic mean.
*Significant differences, over 9.8% performance increase.

Experimental Group has a standard deviation (SD) of 6.78 seconds, with a coefficient of variation (CV) of 4.2%, whereas Control Group has an SD of 8.17 seconds and a CV of 4.8%. The experimental group shows lower dispersion (6.78 sec), indicating greater homogeneity. The control group presents higher variability (8.17 sec). The mean difference between the groups is approximately 9.8 seconds in favor of the experimental group. A CV below 5% in both groups indicates good homogeneity for research purposes.

DISCUSSION

The results of the present study align with findings reported in previous research on neuromotor and integrative neuromuscular training. Akbar et al. (2022) demonstrated that structured neuromuscular programs significantly improve athletes’ physical fitness, including coordination, balance, and agility, which corresponds with the improvements observed in obstacle course performance in our participants. Similarly, Chen et al. (2025) highlighted that integrative neuromuscular training enhances technical execution and movement efficiency, supporting the present findings on reduced movement errors and improved obstacle negotiation. Furthermore, the reduction in injury incidence observed in our participants corroborates the conclusions of Wan et al. (2025) and Peng et al. (2024), who reported that neuromotor and proprioceptive training significantly contribute to injury prevention by enhancing motor control and dynamic stability. Referring to recent studies highlighting the importance of neuromuscular training methods, this research confirms this information through a comparative analysis of the initial and final results obtained by the two experimental groups, A and B. The results reveal that, over a relatively short training period, the level of neuromuscular control of the athletes in group A increased progressively, and their ability to adapt to the complex demands of the obstacle course improved considerably. The study confirms these observations, showing measurable improvements in both completion times and technical performance after a 12-week neuromotor intervention.

An essential aspect is injury prevention, determined by improving the technique and tactics of approaching the running route, with a significant impact on the psychological state of both athletes and coaches.

Looking ahead, it is necessary to expand the research by applying this type of training program to a larger sample of athletes and within different training cycles. At the same time, we aim to compare the results obtained with those generated by other training models in order to identify the most effective methods for individual performance optimization, especially in complex events such as the military pentathlon.

CONCLUSIONS

ü Neuromotor training is a valuable complementary method in military pentathlon training.

ü The neuromotor training contributes to improving performance, strengthening physical endurance, and preventing injuries.

ü neuromuscular training significantly increased performance in girls

ü Future studies with larger samples and varied competitive conditions are recommended to validate the results.

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THE IMPORTANCE OF PHYSICAL TRAINING IN THE ADVANCEMENT OF PARACYCLISTS FROM CATEGORY H1 TO H2 – CASE STUDY

Raluca Maria COSTACHE[1*], Aurora MIHALCEA[2]

ABSTRACT. Paracyclists are part of the category of athletes with lower limb disabilities that require the use of a manually operated bicycle. There are 5 classes of manual cycling, but we present only the categories relevant to the present study, namely: H1: tetraplegics with severe upper limb impairment at the level of the C6 vertebra; H2: tetraplegics with minor upper limb impairment from c7 to t3. ***The purpose of this study*** is to show the importance of physical training in the basic training of tetraplegic cyclists with severe upper limb impairment. ***Materials and methods***: The method of bibliographical study, the method of case study, the method of observation and last but not least, the graphic method. ***Results***: Following the tests performed by the authorized medical personnel of the UCI International Cycling Union, it was found that the I.O athlete can advance to H2 category due to the increase in muscle mass and the improvement of strength in the upper limbs. ***Conclusions***: Following the tests and the applied program, it was found that physical training exercises are beneficial for developing upper limb strength, developing abdominal muscles and are also beneficial for producing power for smooth pedaling

Keyword: physical training, paracyclists, case study

INTRODUCTION

Paracycling emerged in the 1980s, the first Paralympic cyclists were visually impaired and competed in tandem with a sighted partner (Sidwells, 2018).

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Paracycling is a branch of cycling, but it is adapted for people with various motor and locomotor disabilities (Higgins, 2018). It is governed by the International Cyclist Union (ICU) and includes road and track races ("Para-Cycling", 2025).

The first participation in the Summer Paralympic Games took place in New York in 1984, where there were only road races for cyclists with cerebral palsy (Petersen, 2019). During the next four editions of the Paralympic Games, other events were added.

The world's top paracyclists have competed in the World Track and Road Championships since 1994, also in the Commonwealth Games, the Paralympic Games and in 2010 they participated in the World Cup (PARA, 2018).

Handcycling was included in the 2000 Sydney Paralympic Games for the first time as a demonstration event.

Cyclists are classified into three broad groups: visually impaired, cerebral palsy and physically impaired (Friel, 2018). These are further subdivided into 14 functional categories for men and women ("UCI Para-Cycling Road World Championships", 2025). Cyclists are placed in the appropriate category according to their functional capacity as follows:

B: blind (tandem) B1-2

C: bicycle C1-5

H: manual bicycle H1-5

T: tricycle T1-2

The classification for categories H and T is made using the ASIA (American Spinal Injuries Association) assessment test/scale, a test for evaluating patients with spinal cord injuries (SCIs).

The ASIA classification has refined and improved the accuracy of assessing the SCIs patient, providing rigorous, quantifiable data, and is based on the correct recording of neurological examination data.

Physical training is the process of improving physical qualities (strength, endurance, speed and mobility) to optimize performance in a particular discipline or sporting event and to prevent injuries (High Performance Sport New Zealand, 2016). It can be general, aiming at the harmonious development of the body, or specifically, adapted to the requirements of a sports discipline.

Adapted physical training

Paralympic athletes prioritize training that targets their niche (Olson, 2024). Although they can benefit from exercises for the whole body, these competitors often focus on certain parts of the body. For example, a wheelchair cyclist will focus most of their attention on exercises for the upper body.

MATERIAL AND METHODS

The case study was implemented on the I.O. athlete who has a spinal cord injury at the C5-C6 level and benefits from 2 physical training sessions per week and 3 cycling sessions, 2 training sessions on a trainer and one training session on a competition bike in competition conditions (on the road).

This study is both exploratory and explanatory because it shows the importance of physical training in the basic training of tetraplegic cyclists with severe upper limb impairment, to move from category H1 to H2.

For example, below are the training sessions that took place in a weekly cycle.

Physical training workout:

Workout no. 1

-from the sitting position in the wheelchair, perform forward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform backward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform overhead arm raises – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform lateral arm extensions – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform chest throws with a 3 kg medicine ball, 4 sets x 25 repetitions with a 1-minute break between sets

- from the sitting position in the wheelchair, perform overhead throws with a 1 kg medicine ball 3 kg, 4 sets x 25 reps with 1 minute rest between sets

- from the sitting position in the wheelchair perform lateral throws with a 3 kg medicine ball, 4 sets x 20 reps on each side with a 1minute rest between sets

- from the sitting position in the wheelchair perform lateral swings with 3 kg dumbbells, 4 sets x 15 reps with a 1minute rest between sets

- from the sitting position in the wheelchair perform forward swings with 3 kg dumbbells, 4 sets x 15 reps with a 1minute rest between sets

- from the sitting position in the wheelchair perform overhead arm raises with a "Z" bar, with a load of 12 kg, 3 sets x 12 reps with a 1minute rest between sets.

- from the supine position, perform passive thigh flexion on abdomen – 5 sets x 20 repetitions with a 1-minute break between sets

Workout no. 2

-from the sitting position in the wheelchair, perform forward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform Backward arm rotations – 2 sets x 10 reps with a 30-second break between sets
- from the sitting position in the wheelchair, perform overhead arm raises – 2 sets x 10 reps with a 30-second break between sets
- from the sitting position in the wheelchair, perform lateral arm extensions – 2 sets x 10 reps with a 30-second break between sets
- from the sitting position in the wheelchair, perform chest throws with a 3 kg medicine ball, 4 sets x 25 reps with a 1-minute break between sets
- from the sitting position in the wheelchair, perform overhead throws with a 3 kg medicine ball, 4 sets x 25 reps with a 1-minute break between sets
- from the sitting position in the wheelchair, perform lateral throws with a 3 kg medicine ball, 4 sets x 20 reps on each side with a 1-minute break between sets
-from lying on the back on the training bench, perform the flexion and extension of the arms in the elbow joint with the right bar and a load of 25 kg, perform 4 sets x 12 repetitions, with a 1-minute break between sets
-from sitting on the training bench, with the backrest tilted at 45°, perform the forearm flexion on the arm, with the "Z" bar and a load of 20 kg 5 sets x 15 repetitions, with a 1-minute break between sets
- from sitting on the training bench, with the backrest tilted at 45°, perform the forearm extension on the arm, with 8 kg dumbbells, 5 sets x 15 repetitions, with a 1-minute break between sets
- from lying on the back, perform passive thigh flexion on the abdomen – 5 sets x 20 repetitions with a 1-minute break between sets

Cycling training

The training 1

-from the sitting position in the wheelchair, perform forward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets
- from the sitting position in the wheelchair, perform backward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets
- from the sitting position in the wheelchair, perform overhead arm raises – 2 sets x 10 repetitions with a 30-second break between sets
- on the trainer, 10 minutes pedaling at a speed of 10km/h, 20 minutes pedaling at a constant speed of 18km/h, 10 minutes pedaling at a constant speed of 22km/h, 20 minutes pedaling at a constant speed of 18km/h, 5 minutes pedaling at a constant speed of 25km/h, 10 minutes pedaling at a speed of 10km/h.

Workout 2

-from the sitting position in the wheelchair, perform forward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform backward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting in the wheelchair, perform overhead arm raises – 2 sets x 10 repetitions with a 30-second break between sets

-on the trainer, 10 minutes pedaling at a speed of 10km/h, 15 minutes pedaling at a constant speed of 15km/h, 10 minutes pedaling at a constant speed of 12km/h, 15 minutes pedaling at a constant speed of 15km/h, 10 minutes pedaling at a constant speed of 12km/h, 10 minutes pedaling at a speed of 10km/h.

Workout 3

-from the sitting position in the wheelchair, perform forward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform backward arm rotations – 2 sets x 10 repetitions with a 30-second break between sets

- from the sitting position in the wheelchair, perform overhead arm raises – 2 sets x 10 repetitions with a 30-second break between sets

-on the competition bike, under competition conditions, pedal for 160 minutes at an average speed of 20km/h and a maximum speed of 40km/h

Participants

I.O. is a 47-year-old male athlete, and he has spinal cord injury at the C5-C6 level, with complete type A spinal cord section as well as complete loss of trunk stability. Participation in the study mentioned above was voluntary.

Procedure

The ASIA test scale was used, which involves the use of a force intensity rating scale with grades from 0 to 5, on muscle groups important to the practiced sport.

0=absent intensity, no palpable or visible contraction is detected

1=very weak intensity, visible or palpable contraction in the form of intramuscular tensions and/or at the insertion tendon level

2=weak intensity, voluntary movement is performed with full amplitude in the absence of gravity

3=medium intensity, full amplitude of movement against gravitational force. Segmental muscle strength is of “non-functional” intensity, unable to “lock” the joint in a functional kinetic chain

4=good intensity, full amplitude of movement performed antigravitational and against moderate resistance.

5=normal intensity, full range of motion, performed against gravity and normal resistance considering the age, sex and general development of the individual.

Materials

ASIA test scale, stopwatches, break test, wheelchair, trainer, 3kg medicine ball, Z bar, 8kg dumbbells, straight bar, training bench, Polar pulse tester, bibliographic study, observation method.

RESULTS

According to ICU regulations, the testing was carried out by ICU physiotherapists at the end of one of the international competitions in which athlete I.O. participated, results that are confidential for both the athlete and the public.

The sports results had improvements in terms of time spent during international races in both the 21km and 50km races.

Table 1. Diameter of the brachii biceps

Name and surname	Diameter of the brachii biceps		
	Initial	Intermediary	Final
	Left/right	Left/right	Left/right
I.O.	32/30	33/31	34/32

DISCUSSION

The current analysis highlights a clear dichotomy between the empirical approach of amateurs and the methodological rigor of professionalism in cycling. A major barrier to the progress of recreational athletes remains their confinement within the “gray zone” of intensity—a phenomenon that reinforces the necessity of adopting the polarized training model advocated by Friel. In contrast to suboptimal, unorganized effort, polarization ensures a distinct demarcation between recovery and the stimulation of upper physiological thresholds, transforming training from a mere accumulation of mileage into a true engine of performance.

This methodological evolution is intrinsically linked to the technical progress of the racing bicycle. As Higgins (2018) emphasizes, technological innovation has redefined the bicycle, transforming it from a rudimentary vehicle into a sophisticated speed machine. In this context, performance is no longer an exclusively biological attribute but the result of a synergy between physiology and engineering. This is particularly evident in para-cycling, where modern functional classification systems (High Performance Sport New Zealand, 2016) and the professionalization of the discipline noted by Olson (2024) have shifted the focus from social integration toward biomechanical excellence. Thus, physical limitations are no longer viewed as deficiencies, but as optimization parameters within a "laboratory" where the boundary between human and machine becomes increasingly blurred.

However, this race toward optimizing every watt produced raises ethical and pragmatic questions regarding the essence of the sport. The critique provided by Petersen (2019) serves as a necessary counter-argument, reminding us that excessive standardization and high equipment costs may eclipse the human and recreational dimensions of cycling. Ultimately, while the tactics described by Sidwells—such as "chess on wheels" and the dynamics of drafting—underscore the technical complexity of this individual sport played as a team, long-term success depends on the fragile balance between scientific rigor and the intrinsic pleasure of riding.

CONCLUSIONS

Following the tests and the applied program, it was found that physical training exercises are beneficial for the development of upper limb strength, the development of abdominal muscles and is also beneficial to produce power for smooth pedaling.

Physical training exercises also brought considerable benefits in cycling races, because athlete I.O. finished the races in the H2 category approximately 30 minutes faster than in the H1 category.

Physical training led to an increase in muscle mass, at the level of the biceps brachii muscle, increasing by 1cm every 3 months.

Physical training led to the physiological adaptation of strength development in endurance mode.

AUTHOR CONTRIBUTIONS

Author 1, author 2, contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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A STUDY ON THE IMPACT OF SPECIAL EDUCATIONAL NEEDS ON BALANCE AND GENERAL COORDINATION IN MIDDLE SCHOOL CHILDREN IN MAINSTREAM EDUCATION

Florin COTOS[1]*, Bogdan-Constantin UNGUREAN[2]

ABSTRACT. The difficulties to integrate children with special educational needs (SEN) who attend physical education and sports classes in mainstream education endanger the achievement of school physical education objectives, with long-term effects, lack of movement leading to posture deficiencies, worsening of general health, low self-esteem, and deficient morpho-functional parameters. As more and more parents choose mainstream education for students with SEN, the need to identify solutions that help to integrate these children, including physical education classes too, becomes acute. The purpose of this study is to analyze whether there are differences between the results obtained by middle school children, with or without SEN, from the mainstream education system, in tests on static balance and general coordination. The study, which was conducted between April and June 2025, at the "Grigore Ghica Voievod" Secondary School in Suceava, involved 111 students (44 girls and 67 boys), of whom 19 had SEN (8 girls and 11 boys). The Flamingo Test was used for static balance, and the Matorin Test for general coordination. From the analysis of the results obtained, differences were observed between the two groups, with children without SEN recording higher motor parameters. The results obtained have confirmed previous research showing that special educational requirements affect balance and general coordination.

Keywords: special educational needs; static balance; general coordination.

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INTRODUCTION

Recent studies have drawn attention to the difficulties of integrating children with special educational needs (SEN) into mainstream education (Mag, 2023) in Romania. In particular, integration problems also occur in children with SEN who attend physical education and sports classes in mainstream education. Integration problems endanger the achievement of school physical education objectives, with long-term effects, i.e. lack of movement leading to poor posture, worsening of general health, low self-esteem, and deficient morpho-functional parameters (Dante et al., 2020).

The term Special Educational Needs (SEN) first appeared in Great Britain in the Warnock Report (1978). The concept was adopted by UNESCO in the 1990's and referred to the additional educational needs of certain categories of people in difficulty.

In June 1994, the Salamanca Declaration on Special Education, adopted after the UNESCO World Conference, affirmed the right to education, in an inclusive educational system, for every child with SEN, without discrimination and on an equal basis with other children.

Approximately 25 years after the Salamanca Declaration (UNESCO, 1994), there is a increasing trend towards educating students with SEN in mainstream schools (European Agency for Special Needs and Inclusive Education, 2018). In Europe, 4.4% of all students have confirmed SEN, and almost a third of them were educated together with their peers without SEN (Tommetten et al., 2021). In the USA, students with SEN represent 14.5% of all students attending public schools, and in the UK, 13% of students with SEN study in mainstream schools.

As in Romania there is a growing trend of educating students with SEN in mainstream schools too, the need to identify solutions that help to integrate these children, including in physical education classes, is acute. The subject is of great relevance in most states that have adopted the principles of the Salamanca Declaration, a significant increase in the presence of scientific publications on inclusion in physical education being reported in the last 10 years, mainly from countries such as the USA, Brazil and Spain (Marín-Suelves & Ramón-Llin, 2020). In order to diversify the range of solutions for integrating children with SEN in physical education and sports classes in mainstream education, we resolved to analyze whether *SEN of middle school students can influence the results in motor tests*. Static balance and general coordination were tested.

Therefore, we believe that this research will contribute to strengthening the scientific basis in the field and will provide useful information for the integration of children with SEN in physical education classes within mainstream education.

MATERIAL AND METHODS

Participants

The study was conducted between April and June 2025, at the "Grigore Ghica Voievod" Secondary School in Suceava.

The research subjects are secondary school students, enrolled at this school, with and without SEN, attending mainstream education.

The assessment of motor parameters was carried out on all secondary school students (grades V - VIII), i.e. 111 students (44 girls and 67 boys), of which 19 with SEN (8 girls and 11 boys).

The research subjects are of different ethnicities and religious denominations. They, together with their parents or legal guardians, gave their consent to participate in the research.

The testing of motor parameters was carried out according to the methodology, in the gym at the "Grigore Ghica Voievod" Secondary School in Suceava, during physical education classes, with the joint participation of students with and without SEN.

Procedure

a. Static balance – it was assessed using the Flamingo Test

The Flamingo Test is a component of the Eurofit battery of tests designed to assess balance and fitness. This test focuses specifically on assessing an individual's ability to maintain balance on one leg, imitating the stance of a flamingo bird.

It is widely used due to its simplicity, low cost, and applicability for mass testing across different age groups and populations.

The test is part of a broader set of assessments within the Eurofit battery, which includes other measures of fitness such as flexibility, strength, and endurance.

The Flamingo Test is often used in educational and sports settings to assess balance and postural stability.

Description:

The Flamingo Test requires the participant to stand on one leg, bending the free leg back and holding the leg with the hand on the same side, resembling the position of a flamingo. The objective is to maintain this position for as long as possible without losing balance (Barabas *et al.*, 1996).

b. General coordination – it was assessed using the Matorin Test

The Matorin Test is a method used to assess general coordination in students, focusing specifically on motor skills. This test is part of a broader effort to assess motor coordination, which is crucial for physical education and the overall development of students.

The Matorin Test, along with other coordination assessments, provides information about students' physical capabilities and their potential impact on academic performance.

Description:

A circle with a diameter of 40 cm is drawn on the ground. The athlete is then placed inside the circle, with the soles on either side of the diameter. The subject performs a vertical take-off, with a twist around the longitudinal axis of the body. The test is performed twice, to the left and to the right. The number of degrees is measured. If the athlete lands outside the circle, the test can be repeated only once.

Data analysis

Statistical analysis of the collected data was performed using SPSS V.26.0.

The Levene Test shows us that the variances of the Static Balance variable are not equal in the two groups (Sig. = 0.039), which is why under these circumstances we will consider the results of the Welch Test.

In the case of the Total Coordination variable, we will consider the results of the Independent-Samples T Test, because the Levene Test showed us that in this case the variances of the dependent variable in the two groups are equal (Sig. = 0.177).

We must also note that for all the variables analyzed, the significance threshold (Sig.) is < 0.05, which demonstrates that there are differences in the motor indices analyzed, depending on the SEN.

RESULTS

To test the hypothesis "The SEN of middle school students can influence the results in motor tests" we used the Kolmogorov-Smirnov statistical test to verify the normality of the data distribution for each group of subjects (Table 1) – descriptive statistics generated information regarding the mean value of the motor indices tested, both in subjects with SEN and those without SEN (Table 2), the Independent-Samples T Test was applied to identify possible differences between the means obtained by subjects with SEN compared to those without SEN, while the Welch Test was used when the condition of homogeneity of variances was not met (Table 3).

Table 1. Kolmogorov-Smirnov test values for motor tests

		Kolmogorov-Smirnov			Shapiro-Wilk		
	Special Educational Needs	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Static balance	without SEN	.111	92	.007	.973	92	.050
	with SEN	.169	19	**.158**	.944	19	.309
Total coordination	without SEN	.110	92	.008	.959	92	.006
	with SEN	.244	19	.004	.771	19	.000

The results of the test for normality of data distribution demonstrate that the Static Balance variable has a normal distribution (Sig. > 0.05) in the group of subjects with SEN (p = 0.158). The other variables have values that are different from the normal distribution in both groups of subjects.

Table 2. Mean values of motor indices in subjects with and without SEN

	Special Educational Needs	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Static balance	with SEN	19	**22.42**	2.545	.584
	without SEN	92	**16.89**	3.921	.409
Total coordination	with SEN	19	**433.16**	87.816	20.146
	without SEN	92	**600.76**	95.359	9.942

From the analysis of the data presented in Table 2, we can observe differences between the averages obtained in the motor indices of the group of subjects with SEN, compared to the group of subjects without SEN.

Next, we will present the results of the Independent-Samples T Test. We decided to apply this test, even though the Kolmogorov-Smirnov test showed that the condition of normality of the distribution of the analyzed data was not fully respected, because the Independent-Samples T Test is sufficiently robust as to the violation of this condition. Also, the Welch Test is sufficiently robust as to the violation of the condition of normality of the distribution of the analyzed data.

Table 3. Independent Samples Test results for motor indices, function of SEN

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Static balance	Equal variances assumed	4.343	.039	5.885	109	.000	5.530	.940	3.667	7.392
	Equal variances not assumed			**7.757**	**38.149**	**.000**	**5.530**	**.713**	**4.087**	**6.973**
Total coordination	Equal variances assumed	1.849	.177	**-7.064**	**109**	**.000**	**-167.603**	**23.727**	**-214.628**	**-120.578**
	Equal variances not assumed			-7.460	27.512	.000	-167.603	22.466	-213.659	-121.547

The Levene Test shows us that the variances of the Static Balance variable are not equal in the two groups (Sig. = 0.039), which is why under these circumstances we will consider the results of the Welch Test.

In the case of the Total Coordination variable, we will consider the results of the Independent-Samples T Test, because the Levene Test showed us that in this case the variances of the dependent variable in the two groups are equal (Sig. = 0.177).

We must also note that for all the variables analyzed, the significance threshold (Sig.) is < 0.05, which demonstrates that there are differences in the motor indices analyzed, depending on the SEN.

Static balance: we used the Welch Test because the variances are not equal (Sig < 0.05), the means of the variable in the two groups are different (MA = 16.89 for ss. without SEN and MA = 22.42 for ss with SEN), *t* value (38.149) = 7.757, Sig. < 0.05, **diff. of means = 5.530**, the difference in the mean between subjects with SEN and those without SEN is in the range of 4.087 – 6.973, with a confidence level of 95%.

Total Coordination: we used the Independent-Samples T Test because the variances are equal (Sig. = 0.177), the means of the variable in the two groups are different (MA = 600.76 for without CES and MA = 433.16 for with CES), t value (109) = -7.064, Sig. < 0.05, **diff. means = -167.603**, the difference in the mean between subjects with SEN and those without SEN is in the range -214.628 – -120.578, with a confidence level of 95%.

From the analysis of the results obtained in the research we conducted, differences between the two groups can be observed with regard to motor indices, an aspect that demonstrates that hypothesis was accepted.

DISCUSSION

Special Educational Needs (SEN) have a significant impact on static balance and general coordination, as shown by various studies focusing on children with various disabilities. These studies highlight the challenges that children with SEN encounter in maintaining balance and coordination, as well as potential interventions that can improve these skills. Research highlights the importance of personalized physical education programs and specific training exercises to improve balance and coordination in children with disabilities.

A study shows that students with SEN display notable postural dysfunctions. Children with SEN show poorer balance in various conditions compared to their peers, indicating a significant impact on their static balance skills (Nunzi et al., 2018).

Intellectual disabilities contribute to poorer balance skills as well, which can delay motor development and limit functional levels. Psychomotor education programs have been shown to improve static balance in children with intellectual disabilities (Fotiadou *et al.*, 2017).

Visual impairments affect balance due to the critical role of vision in maintaining posture and executing motor skills. Children with visual impairments often experience reduced physical activity due to their fear of falling, which can further impair their balance and coordination (Metgud & Honap, 2016).

Physical activation programs have been proven to be effective in improving both static and dynamic balance in students with SEN. These programs, which focus on proprioceptive stimulation, have demonstrated significant improvements in balance among students with a variety of disabilities, including intellectual, visual, and hearing impairments (Parvu et al., 2023).

Dynamic neuromuscular stabilization exercises have been beneficial for students with intellectual disabilities, leading to significant improvements in both static and dynamic balance (Dehghani et al., 2023).

Special balance training programs have demonstrated improvements in balance performance among students with SEN, suggesting that such programs can be integrated into the physical education curriculum to improve balance capabilities (Çankaya et al., 2015).

In spite of the benefits of specific interventions, some challenges still remain in addressing balance and coordination problems in children with disabilities. For example, children with SEN may not exhibit balance problems under normal conditions, but experience difficulties in new or unsupervised situations, indicating the need for more nuanced interventions (Geuze, 2005).

The relationship between static balance and fundamental motor skills in children with visual impairments is complex, with studies that show no significant correlation, suggesting that other factors may influence the development of motor skills in these children (Metgud & Honap, 2016).

Although interventions such as core motor activation and psychomotor education programs have proven to be promising in improving balance and coordination in children with special educational needs, the efficiency of these programs may vary depending on the type and severity of the disability. In addition to this, the small sample sizes and short durations of some studies suggest that further research is needed to generalize findings and optimize intervention strategies. Understanding the specific needs and challenges of each disability is paramount for developing effective educational and training programs that can improve balance and coordination in children with special educational needs.

CONCLUSIONS

The analysis of the results obtained in the motor tests showed statistically significant differences between the group of students with SEN and that of students without SEN. Our results are also supported by the technical literature in the field.

This study also highlights the need for strategies that bring children with SEN closer to physical activities. The benefits of physical activity on the health of children with SEN are presented in more and more studies, and physical education classes represent a good opportunity to step up in order to increase the quality of life of the children with SEN enrolled in the mainstream education system.

The involvement of teachers, parents and social support are indicated as beneficial psychosocial resources for the integration of children with SEN in the physical education class in mainstream education.

AUTHOR CONTRIBUTIONS

Author 1 and author 2 contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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PILOT STUDY ON THE DEVELOPMENT OF HAND-EYE COORDINATION IN THEORETICAL HIGH SCHOOL STUDENTS

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ABSTRACT. ***Introduction***: the study addressed the development of hand-eye coordination in high school students with a theoretical profile, recognizing its importance in both sport and cognitive performance. ***Objective***: the aim of the research was to examine the effects of a structured five-week training program on reaction time, coordination, and fine motor skills among adolescents. ***Material and methods***: three students, aged 15–16 years (two males and one female), participated in the study. All had prior experience with school handball training. the program was implemented over five weeks, with three sessions per week, each lasting 60–75 minutes. Ten exercises were included, such as ruler drop, reaction to cups with auditory cues, tennis ball drop at different levels, wall toss, and finger tapping. difficulty, repetitions, and tempo were progressively adjusted based on individual performance. ***Results***: preliminary findings indicated improvements in reaction time, bilateral coordination, and fine motor dexterity, with estimated progress of 10–15%. The greatest gains were observed in exercises emphasizing rhythm and accuracy. individual differences were noted, and the role of varying pauses, auditory cues, and exercise sequencing appeared to influence outcomes. improvements became evident after two weeks and were confirmed in the intermediary evaluation. ***Discussion***: the results were consistent with existing literature supporting the role of progressive coordination training in enhancing perceptual-motor abilities. The small sample size limited generalization but highlighted practical tendencies for future validation. ***Conclusions***: structured coordination training improved hand-eye coordination in adolescents. Future research with larger samples is recommended to establish broader applicability, especially for goalkeepers in theoretical high schools who have limited access to specialized programs.

Keywords: hand-eye coordination, high school students, training program, reaction time, motor skills, handball.

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INTRODUCTION

Even at the school sports level, we need to take into consideration developing psychomotor abilities such as eye-hand coordination, as modern athletic performance requires an interdisciplinary approach, in which psychomotor control plays a key role (Predoiu, 2015). Hand-eye coordination, a specific feature of the physical fitness, is effectively developed through competitive sports that engage the upper limbs. (Kaluga et al., 2020). This capability is fundamentally biometric and is closely related to other very important components of physical fitness such as speed, strenght or endurance (Kasmad et.al., 2020). It is an important component of the overall physical base, bearing in mind that physical conditioning serves as a vital supporting factor for basic technical execution in sports (Candra, 2020). It plays a crucial role in acquiring sports skills. (Stricker, 2002, as cited in Yadav, 2019). Also, eye-hand coordination is not only a sport aspect; it is a fundamental skills, very important for accurately executing everyday tasks that involve reaching, grasping or manipulating objects (Niechwiej-Szwedo, 2021).The primary rationale for this pilot study is to develop an accessible training program that can be utilized by the most physical education teachers, irrespective or heavy financial or time constraints. The proposed methods, materials, and tests are intentionally easy to acquire and implement, ensuring broad availability for an PE instructor. Handball players needs specific training to efficiently perform during the intermittent and demanded phases of the match (Gabrys et. al, 2020).

For a goalkeeper, speed and agility are paramount, and the quality of their movements is critically determined by underlying factors such as visual processing, reaction time, and perception (Eler & Eler, 2020). Furthermore, spatial anticipation plays a vital role, defined as the ability to predict the time and location where an object, such as a ball in team sports, will appear (Krawczyck et al., 2017). Therefore, an effective program must integrate exercises that specifically target both the speed of movement and the cognitive components of visual-motor processing. Hand-eye coordination represents a complex process involving the integration of ocular and manual motor systems. The execution of precise, timely, and skillful actions – such as reaching for or grasping small objects – relies on accurate visual information about surrounding environment and the simultaneous control of eye and hand movements (Rizzo et al., 2020).

Hand-eye coordination is fundamentally dependent on proprioceptive control. This control mechanism is essential not only for the optimization of sports performance and daily life activities but also for rehabilitation in medical conditions. In this context, studies show that proprioceptive deficiencies, which can manifest from early ages have direct effects on movement regulation (Szabo et al., 2021).

MATERIAL AND METHODS

Participants

The participant group consisted of a small, non-random convenience sample of three high school students (N=3; two males, one female) recruited from Regina Maria Highschool in Dorohoi, Romania. Participants ranged in age from 15 to 17 years. A key inclusion criterion was the absence of prior formalized training or competitive experience in performance sports or registered handball clubs, ensuring that the observed improvements could be predominantly attributed to the intervention program. The values from the next table are presented in cm, except the weight.

Table 1. Subjects measurements

Subject	Height	Waist	Weight	Bust	Length of arms	Length of lower limbs	Wingspan	Arm circ.
S1	175 cm	72 cm	65 kg	83 cm	80 cm	103 cm	184 cm	25 cm
S2	182 cm	91 cm	84.0 kg	97 cm	76 cm	94 cm	180 cm	30 cm
S3	177 cm	73 cm	62.7 kg	86 cm	79 cm	95 cm	178 cm	29 cm

The study was conducted with 3 students from Regina Maria Highschool Dorohoi. Their age is between 15 and 17. Two subjects are male and one female. Is important to mention that none of them had prior experience in performance sports or handball clubs. All of them were healthy, had a normal or corrected-to-normal vision and provided voluntary consent to participate. Also, because they are minors, written consent was also obtained from their parents.

The working hypothesis of the study stated that a progressive hand-eye coordination training program would produce a general improvement in motor performance ranging between 10-15%, reflected in enhanced reaction time, bilateral coordination, and fine motor execution speed.

The research questions are:

1. To what extent can a progressive hand-eye coordination program improve visuomotor reaction time in highschool students?
2. What is the impact of differentiated coordination exercises on bilateral control and precision of execution?

The experimental study took place at the Regina Maria Highschool in Dorohoi, Botoșani County, Romania. The intervention was structured over a four-week period, which included three evaluation stages. The initial testing was conducted on September 8, 2025, followed by the intermediate evaluations on September 23, 2025, and the final evaluation on October 6, 2025. The training program consisted of three sessions per week. Each training session lasted between 45 and 60 minutes and was designed to be highly concentrated. A key component of the protocol was the inclusion of all six primary exercises in every training session. This approach ensured continuous, balanced exposure to all perceptual motor demands, with the difficulty, repetitions, and tempo being progressively adjusted over time to maintain a high intensity and optimize individual progress.

A total of six exercises were used in this study for the development of hand-eye coordination. The exercises were related to the evaluation test, plus they needed to be adjusted to the participants' skill levels. They were simple in design and were progressively modified, following the principle of decreasing volume while increasing intensity over time.

First exercise – Ruler Drop

The training protocol applied a progressive overload model. Initial, the process starts with an acclimation of the participant with an initial drop height of 10 cm. Volume was systematically increased from two to three sets of 10 drops. The final phase intensified with sets of 10 drops from 5 cm, ensuring a high-intensity preparation for the measurements.

Second exercise – Two Tennis Ball Drop

The Two-Tennis Ball Drop Test assessed choice reaction time, requiring the participant to catch one of two randomly released tennis balls before hit the ground. The protocol applied three progressively difficult levels based on the drop height: Level I (shoulder height), Level II (intermediate height), and Level III (hip height). Training volume was progressively increased at each level, gradually introducing higher difficulty levels.

Third exercise – Alternate Hand Wall Toss

The exercise required participants to stand two meters in front of a wall and repeatedly throw a tennis ball with one hand while catching it with the other for 30 seconds. The wall was divided imaginatively into three zones (low, medium, and high) to help participants identify optimal target areas. Starting point was from one set of three repetitions focused on technique and rhythm, then progressed to two and finally three sets.

Fourth exercise – Modified Multiple Choice Reaction Time Drill

The exercise is adapted from the cone test, was conducted indoors due to unfavorable weather. Participants performed reaction speed tasks in response to auditory cues, by touching one or more cones placed on a desk. The exercise had three levels of difficulty, with higher levels included synchronized arm-leg movements to stimulate goalkeeper reactions. Directional commands ("left," "center," "right") and cues ("Stop" or "Move") were used to test reaction time and coordination.

Fifth exercise – Red Light, Green Light reaction drill:

The exercise was based on the classical "Red Light, Green Light" reaction test and was used throughout the program primarily for consolidation purposes. The task remains identical to the evaluation test: subjects had to react as quickly as possible to the visual stimuli (green light) displayed on the smartphone screen, following a red signal. The exercise was repeated systematically during the training sessions, maintaining the same structure, to improve reaction consistency and reduce variability in response time. Regular repetition also aimed to strengthen concentration and to stabilize visual-motor coordination.

Sixth exercise – Tap Test Simulation

The sixth exercise consisted of repeated simulations of the Tap Test, designed to enhance fine motor control and hand movement frequency. During the activity, the subject was seated on a chair with a desk in front. The arm was positioned on the table, extend from the elbow joint, with the hand placed above the smartphone screen. Each repetition lasted 10 seconds, during which the participant tapped the screen as quickly as possible.

First test – Ruler drop test

The ruler-drop test is a standardized test, applicable both in sports performance evaluation and in medical rehabilitation, particularly for concussion assessment and recovery monitoring (Del Rossi et. al, 2014).

Purpose: Determination of the reaction visual-motric time. Materials: 30 cm wood ruler, classroom. Procedure: The test was held like this: the subject stood upright at a distance of approximately half a meter from the examiner. The examiner held the 30cm ruler vertically, with the 0 cm mark aligned with the subject's fingers. The ruler was released randomly, without any other signals. The subject's task was to catch the ruler as quickly as possible after release, and to be as close as possible to the lowest point of the ruler.

Second test – Two Tennis Ball Drop Test

This test is a practical method to asses hand-eye coordination and reaction time using random stimuli. Similar protocols using reaction ball have been shown to significantly improve hand-eye coordination and speed response in athletes (Lenik et al., 2017).

Purpose: To evaluate reaction time and hand-eye coordination under random stimuli. Materials: Two tennis balls, classroom. Procedure: The examiner stood in front of the participant at a distance of approximately 1.5 meters, holding one tennis ball in each hand. The balls were positioned at shoulder lever of the examinator. The subject stood relaxed, with arms by their sides. Without any signal, the examiner released one of the tennis balls, and the participant had to catch it before it touched the floor. The tennis balls were released randomly.

It was counted the number of tennis balls caught, touched or missed. Also, we counted the hand from which the ball was released (left or right). Each participant performed 10 repetitions at shoulder height.

Third test: Multiple Choice Reaction Time Test

Purpose: To assess reaction time in situations with multiple motor response options, typical in oppositions sports. Materials: 3-4 cones, digital stopwatch, smartphone (for recording), flat area (40x20m field). Procedure: The subject stood at the starting line in a reaction stance with slightly bent knees. One, two or three cones were placed 5 meters ahead, depending on the level of the test level. The examiner randomly announced a direction (left, center or right), and the subject had to move as quickly as possible to touch the indicated cone. Timing stopped when the subject touched the cone. Each level included six trials, and the final score was the average of the recorder times.

Fourth test – Alternate Hand Wall Toss Test

The Alternate Hand Wall Toss Test is considered a valid, and reliable measure of dynamic hand-eye coordination. Its validity was demonstrated in a large-scale study on Korean children (n = 2753), where researchers confirmed the capacity of the test to distinguish coordination levels based on adequate wall distance (Cho et al., 2020)

Purpose: To evaluate bilateral coordination and manual reaction speed**.** Materials: Tennis ball, smooth wall, stopwatch**.** Procedure: The subject stood 2 meters from the wall. The task was to throw the ball with one hand and catch it with the other continuously for 30 seconds. Each participant performed two sets of 30 seconds. If the ball dropped, the participant continued the exercise, but the number of errors and successful throws was recorder.

Fifth test – Red Light Green Light Test (University of Washington)

The Red Light Green Light Test is a valid method to asses simple visual reaction time using a mobile device. Prior research shows that smartphones can accurately measure reaction times in response to visual stimuli, fact that provides validity and the possibility of reproductibile results (Burke et al., 2017). Purpose: To determine visual reaction time to light stimuli. Materials: Smartphone with internet connection. Procedure: The subject sat on chair with the forearm resting on a table and with the hand above the smartphone. The app simulated a traffic light, staring with red light. The subject had to press the screen as quickly as possible when the green light appeared. Each participant completed five repetitions, and the average reaction time was calculated.

Sixth test – Tap test

This test is validated for assessing fine motor speed and neuromuscular integrity. Although this aspect was traditionally administered by specialized devices, recent research confirms that the use of a smartphone application demonstrates acceptable reliability and known groups validity (Bohannon & Wang, 2021).

Purpose: To evaluate motor reaction speed and finger tapping frequency. Materials: Smartphone with internet connection. Procedure: The subject sat on a chair with the forearm resting on a table and the hand above the touch screen. After starting the app, the participant triggered the timing by pressing a button. The participant had 10 seconds to perform as many progressive raps on the screen as possible. The number of taps was automatically recorded by the app.

RESULTS

Ruler Drop Test – Results and Interpretations

According to the testing protocol, each participant performed three trial attempts before every evaluation phase, with a 15-second pause between the familiarization and the actual testing series. The mean value for each stage was calculated based on six valid attempts, in order to minimize the effect of random error and enhance measurement reliability.

Subject 1 started with a mean value of 13.16 cm, registering two peak values of 17 cm during the initial testing. During the intermediate stage, the results became more stable, ranging between 5 and 12cm, indicating a visible improvement in consistency and reaction control. At the final evaluation, the average results remained within the 11-12 cm range, suggesting that the subject maintained the achieved progress and developed a steady visuomotor response pattern. Compared to the three initial values above 13 cm, the subject demonstrated a clear evolution toward faster and more controller reactions. Subject 2 showed the most significant improvement. Starting from maximum initial values around 16 cm, the participant progressed to the point where no value exceeded 9 cm at the final testing, achieving a best score of 5 cm. Subject 3 also displayed measurable improvement. While the initial test included three values above 12 cm, the final evaluation presented stable scores between 9 and 10 cm, indicating enhanced attention and timing accuracy.

Overall, all three participants exhibited progress between the initial and final measurements. The greatest changes were recorder between the first and second stages, where adaptation and concentration mechanism appeared to consolidate. The final results confirm that the progressive coordination program contributed to faster visuomotor reaction times and a reduction in performance variability, especially for Subjects 1 and 2.

Table 2. Results of the first test

SUBJECT	INTIAL	INTERMEDIATE	FINAL
Subject 1	13.16 cm	11.6 cm	12.1 cm
Subject 2	12.16 cm	14.1 cm	7.6 cm
Subject 3	10.3 cm	11.8 cm	9.16 cm

Second test – Two Tennis Ball Drop Test

The performances in this test showed significant progress compared to the initial evaluation. However, the main difficulty was not related to the number of dropped balls, but rather the number of tennis balls touched without being caught.

Starting from the intermediate stage, both Subject 1 and Subject 3 began to convert their touches into successful catches – each improving by two balls on average. Their progress continued during the final testing, where Subject 1 added two more caught ball, and Subject 3 added one additional successful catch. The total number of errors (missed balls) decreased progressively – from four in the initial test, to three in the intermediate, and finally zero in the last stage. The reduction demonstrates a clear improvement in control, anticipation, and catching precision.

The main reasons for these improvements include: working through progressive difficulty levels, where the other two training levels were more challenging than the one used in testing, improvements of catching technique, with a more relaxed hand and adjusted finger positioning to reduce strong contact and prevent ball deflection, inclusion of the wrist relaxation drills, which helped increase fluidity and reaction efficiency during the catching movement

These technical adjustments, combined with repeated exposure to variable stimuli, likely contributed to a learning effect, reflected in better timing, anticipation, and decision-making speed.

Legend of the table: C – catched tennis balls, T – touched, M – missed

Table 3. Results of the second test

SUBJECT	INITIAL	INTERMEDIATE	FINAL
Subject 1	C – 3, T – 4, M – 2	C – 7, T – 2, M – 1	C – 9, T – 1, M – 0
Subject 2	C – 2, T – 5, M – 2	C – 1, T – 7, M – 1	C – 9, T – 1, M – 0
Subject 3	C – 7, T – 3, M – 0	C – 8, T – 1, M – 1	C – 9, T – 1, M – 0

Third test: Multiple Choice Reaction Time Test

The Multiple Choice Reaction Time Test did not show significant changes in reaction times over the course of the study. However, improvements were observed in technique and efficiency. Notably, subjects demonstrated better movements trajectories and were increasingly able to avoid the tendency to move in the opposite direction of the announced target. These refinements are particulary relevant for decision-making in handball goalkeepers, as they enhance the ability to react accurately and efficiently during gameplay. An important aspect of the test was the inclusion of difficulty-based levels. The differences between the first two levels, however, are minimal. The values in the table are in seconds.

Table 4. Results of the third test

SUBJECT	INITIAL	FINAL
Subject 1	I – 1.99, II – 1.92, III – 1.95	I – 1.77, II – 2.17, III –2.77
Subject 2	I – 1.81, II – 1.90, III – 1.92	I – 1.84, II – 2.09, III – 2.00
Subject 3	I – 1.64, II – 1.77, III – 1.69	I – 1.65, II – 1.87, III – 1.76

Fourth test – Alternate Hand Wall Toss Test

Significant improvements were observed from the first assessment, particularly in the intermediate evaluation. Subject 1 demonstrated the most notable progress, reducing errors from 9 in the initial 2 series of 30 seconds to only 4 in the final assessment, and even achieving 0 errors during the intermediate evaluation.

All three subjects showed substantial gains in tennis ball-catching performance. Subject 1 improved from 10 catches in the initial evaluation to 24 in the final assessment, with the intermediate evaluation reaching 26 catches, close to the final maximum of 25. Subject 2 also progressed, achieving 29 catches in the final assessment compared to 23 initially and 25 in the intermediate evaluation. Subject 3 developed greater stability, increasing from a maximum of 21 catches in the first evaluation to 27 in the final one.

Key factors contributing to these improvements included focusing on imaginary target zones to ensure direction, control and stability during throws, and performing movement on the tennis balls of the feet, which promotes continuous motion – a critical skill for handball goalkeepers. In the table, the values in parentheses represent: the first value - the number of balls caught, the second value - the number of errors (or mistakes).

Table 5. Results of the fourth test

SUBJECT	INITIAL	INTERMEDIATE	FINAL
Subject 1	I (8-5)/2 (10-4)/A (10-5)	I (26-0)/2 (26-0)/A (26-0)	I (23-2)/2 (25/2)/A (24-2)
Subject 2	I (19-1)/2 (23-0)/A (10-5)	I (26-0)/2 (26-0)/A (26-0)	I (29-0)/2 (25/3)/A (27-2)
Subject 3	I (21-0)/2 (18-1)/A (19,5-1)	I (20-0)/2 (21-0)/A (20.5 – 0)	I (27-0)/2(22-3)/A (25-2)

Fifth test – Red Light Green Light Test (University of Washington)

The Red Light Green Light test showed minimal differences in scores compared to other assessments. However, the key improvements was observed in participants' decision-making and technique. Subjects became increasingly able to quickly choose between two colors and respond as accurately as possible.

Table 6. Results of the fifth test

SUBJECT	INITIAL	FINAL
Subject 1	0.4402	0.436
Subject 2	0.4718	0.577
Subject 3	0.4	0.439

Sixth test – Tap test

All three subjects showed improvement from the initial to final assessment, indicating overall gains in hand-eye coordination and execution speed. The marked increase between the intermediate and final evaluations for Subjects 2 and 3 suggests that the prior exercises focused on coordination and catching had a cumulative effect, preparing the subjects to perform the test more efficiently. The results from the table show the number of taps.

Table 7. Results of the sixth test.

SUBJECT	INITIAL	INTERMEDIATE	FINAL
Subject 1	73	74	76
Subject 2	71	77	97
Subject 3	68	68	87

DISCUSSION

As noted by Baloga & Șandor (2019, p. 73), "the most important asset for a basketball player is the coordination of the body and mind, defined as the minimum effort made in order to obtain the easiest and almost perfect shot to the basket." This statement encapsulates the essence of hand–eye coordination as a fine-tuned process of perceptual regulation and motor precision. Building on this concept, educational programs that cultivate rhythmic control, stable postural alignment, and visual focus can effectively translate high-performance motor control principles into physical education contexts.

Negru (2023, p. 50) emphasized that "balance is defined as quick postural adaptation against changes in the centre of gravity at the time of activity." This finding underscores the biomechanical foundation of dynamic balance as a prerequisite for efficient coordination. Although no direct correlation was found between strength and balance measures, the study revealed improvements in successive balance trials, suggesting that repeated exposure and attentional calibration enhance stability through practice.

Balla & Hanțiu (2017, p. 114) found that "the degree of trunk asymmetry was lower in subjects who live in rural areas compared to those from urban environments," linking habitual physical activity with postural alignment and proprioceptive equilibrium. Such evidence indicates that natural movement variety and frequent engagement in physical activity contexts reduce asymmetrical load patterns, which in turn support eye–hand coordination and motor balance among youth populations.

Prodea & Pătrașcu (2011, p. 33) reported that "the need to continuously improve the motoric learning led up to an increased attention towards the mental algorithms that influence learning." Inaccurate verbal or visual cues were shown to disrupt the encoding of motor responses, highlighting the pedagogical importance of precise and consistent communication during coordination-based instruction. This reinforces the role of clear feedback and reinforcement in optimizing motor learning efficiency.

These findings suggest that coordination development among students is multifactorial shaped by perceptual acuity, balance control, proprioceptive feedback, and communication accuracy. As demonstrated by Baloga & Șandor (2019), Negru (2023), Balla & Hanțiu (2017), and Prodea & Pătrașcu (2011), structured yet adaptable practice environments that emphasize both cognitive engagement and physical stability yield sustainable improvements in reaction time and hand–eye synchronization.

LIMITS

This pilot study has several limitations, primarily due to the small sample size (N=3, understandable given the highly niche focus on theoretical high school students). A key constraint is the reduced five-week intervention period, which limits the observation of long-term skill retention. Nevertheless, the structured program demonstrated numerous positive trends and can serve as an effective foundation for future research with the perspective of observing sustained improvements over a longer period.

CONCLUSIONS

The working hypothesis, anticipating a 10-15% general improvement, is confirmed and significantly surpassed by most of the results of the five-week intervention. The structured training effectively enhanced perceptual motor skills, particularly in complex tasks. For example, bilateral dynamic coordination (Wall Toss Test) improved by 50,50%, with not many changes concerning the mistakes, bearing in mind the fact that in the intermediate evaluation all of the subjects had 0 mistakes. The reduction of errors in the Two Tennis Ball Drop demonstrated a 100% elimination of missed tennis balls and a 125% increase in successfully caught tennis balls.

Regarding first research question, we can affirm that both the Ruler Drop Test and Two Tennis Ball Drop Test indicated consistent improvement in visuomotor reaction, especially after the intermediate evaluation phase. The adaptation of neuromotor pathways, combined with visual anticipation drills, contributed to faster and more stable reactions. Anticipation skills were particularly developed through the strategies adopted by the subjects during the Alternate Hand Wall Toss Test.

Concerning the second research question, observable improvements were noted in attention control and motor response stability. Repetition and task variation enhanced selective attention and visual regulation, resulting in more consistent performance and reduced variability across trials. In the Tap

Test, participants demonstrated greater focus and rhythm, maintaining a constant tapping frequency throughout the 10 seconds interval, with fewer pauses or missed taps.

AUTHOR CONTRIBUTIONS

Alexandru Andrei GHERMAN, Albert OSTAFE, and Leon Gomboș contributed equally to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript. All authors had equal rights and responsibilities in the preparation of this work. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest related to this research.

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IMPACT FORCE IN SHOULDER DISLOCATION TRAUMA IN TEAM SPORTS

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ABSTRACT. This scientific paper presents the biomechanical aspects of the kinetics of the collision of two athletes, with consequences on the traumatism of shoulder dislocation, as well as the ways to reduce the impact force to avoid injury. Using the value of the coefficient of restitution upon collision, based on previous own research, the analytical expression of the impact force is determined, this depending on the instantaneous velocities before and after the collision, on the coefficient of restitution and on the masses of the two athletes. Shoulder dislocation occurs due to the force acting on the humeral head and the joint dislocation from the glenoid cavity of the scapula, this force being the impact force upon collision. Using the game of rugby as an example, the impact forces are calculated for several collisions during a sports competition and then compared with the joint resistance force above which the shoulder joint dislocation can occur. This last force is determined taking into account the mechanical rupture stresses of the articular ligaments, muscles, joint capsule and bone tissue. The paper presents a numerical simulation for determining the pre-collision velocities, for different masses of athletes, so that posterior shoulder dislocation occurs. Also, the paper numerically simulates various situations for the joint resistance force that keeps the scapula-humeral joint in normal operating conditions and then compares this with the impact force from the rugby game.

Keywords: joint dislocation, collision force, rugby, prevention, orthosis.

INTRODUCTION

The accidents can be prevented if the player knows details about dynamic impact, impact techniques, how to protect himself during impacts. Thus, there was analyzed the dependence between the frequency and intensity of the impact

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and cervical accidents, for the orderly pile in the game of rugby (Scher, 1987; Milburn, 1993; Quarrie, 2001; Yeomans, 2018), the spinal column accidents (Silver, 1988, 1993, 1994) or knee accidents (Ellapenl, 2016) due to impact during the game.

Shoulder dislocation resulting from accidents in team sports has an immediate effect of incapacitating the athlete for a period, depending on the severity of the trauma (without or with ligament or muscle rupture). The duration of immobilization depends on the type of dislocation, the patient's age, whether it is the first dislocation or a relapse, the level of sports activity, etc. (Cunningham, 2005; Radhik, 2022). An epidemiological study conducted among young athletes in the USA (Twomey-Kozak, 2021) highlighted the fact that most shoulder injuries occur among young athletes, usually amateurs, who have little experience with injuries. Over a five-year period, around 89,500 shoulder dislocations were reported, with injuries occurring in sports such as basketball (24.1%), American football (21%), soccer (7.1%), baseball (7%), etc.

The purpose of this paper is to present a theoretical biomechanical model for evaluating the maximum resultant force given by the muscles and ligaments in the glenohumeral joint and to compare this force, for a human subject, with the values obtained experimentally in the case of a collision between two athletes in the game of rugby.

MATERIAL AND METHODS

For our paper we are interested in evaluating the resultant force with which the ligaments and tendons of the glenohumeral joint act on the humeral head, pressing it into the glenoid cavity of the scapula. The glenohumeral joint is actively stabilized by the rotator cuff (supraspinatus, infraspinatus, subscapularis, and teres minor muscles) and passively by the glenohumeral ligaments and the joint capsule. The resultant force that maintains the humeral head in the glenoid cavity is the vector sum of these contributions.

The evaluation methods currently available are:

• computerized biomechanical modeling: 3D models of the joint, based on MRI or CT images, are used to simulate muscle and ligamentous forces in different positions of the arm. These can estimate the axial compressive force that maintains the humeral head in the glenoid;

• electromyography (EMG) combined with kinematic analysis: EMG measures muscle activity, and motion analysis allows estimation of the direction and intensity of forces. This method is indirect, but provides useful data on the contribution of the rotator cuff muscles;

• cadaveric studies: in research, anatomical samples are used to directly measure the tension of the ligaments and tendons in different positions of the shoulder. These provide approximate values of passive forces;

• advanced imaging (dynamic MRI, functional ultrasonography): can highlight the position of the humeral head and the degree of contact with the glenoid during movement, indirectly suggesting the effectiveness of the compressive forces.

Examples of clinical applications can be:

• in cases of glenohumeral instability, the evaluation of muscle and ligament forces is essential to decide between conservative treatment (kinesiotherapy) and surgical intervention;

• in rotator cuff arthropathy, the loss of compression force leads to humeral head migration and joint degeneration.

The exact values of the resultant force vary depending on the arm position, muscle tone and ligament integrity. Studies suggest that the rotator cuff can generate compressive forces of over 100 N in functional positions, but these figures are estimates and depend on the calculation method [6,7].

To develop a biomechanical model to evaluate this force, we will consider: the supraspinatus, infraspinatus, subscapularis muscles and the superior, middle and inferior glenohumeral ligaments. We adopt an axis system with the origin at the center of the humeral head. The x-axis will be horizontal and parallel to the sagittal plane. The y-axis will be vertical and parallel to the sagittal plane. The z-axis will be horizontal and parallel to the frontal plane (figure 1).

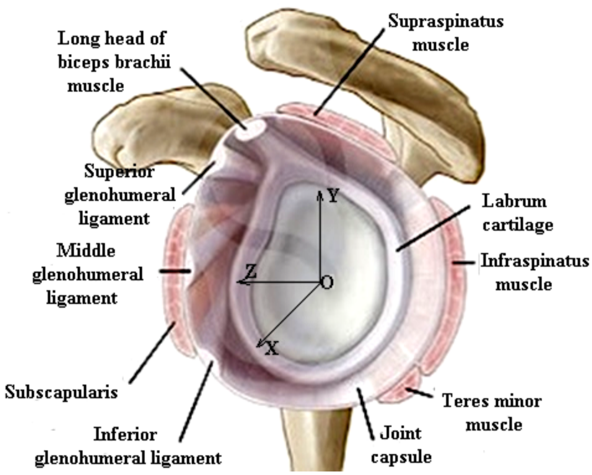

Fig. 1. The axis system with the origin in the center of the humeral head of the right shoulder (Funk, 2025)

In figures 2 and 3 see the axis system originating in the center of the humeral head of the right shoulder and the points of application of the forces exerted on the humeral head by the supraspinatus, infraspinatus, subscapularis muscles and the superior, middle and inferior glenohumeral (GH) ligaments.

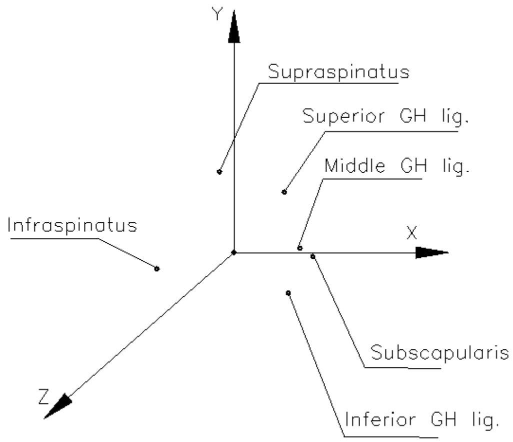

Fig. 2. The axis system with the origin in the center of the humeral head of the right shoulder and the points of application of forces on the humeral head (xy plane view) (original drawing by the authors)

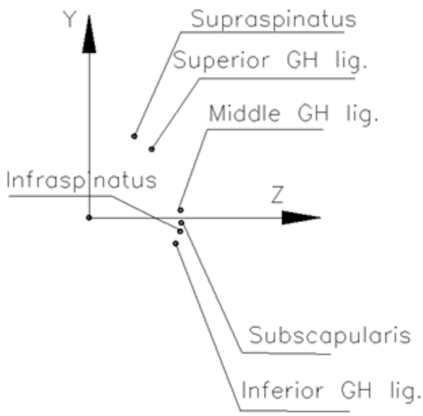

Fig. 3. The axis system with the origin in the center of the humeral head of the right shoulder and the points of application of forces on the humeral head (view in the yz plane) (original drawing by the authors)

The diameter of the humeral head in the adult male is on average between 43 and 52 mm. This value can vary slightly depending on height, constitution and ethnicity. In men, the size is generally larger than in women, due to the more developed bone and muscle mass. We will consider an average value of 49 mm.

In table 1 are presented average estimated values of the x, y and z coordinates for the application points shown in figures 2 and 3.

Table 1. The values of the geometric coordinates of the insertion points

Element (muscle or ligament)	X (mm)	Y (mm)	Z (mm)
Supraspinatus muscle	-4.37	24.33	11.64
Infraspinatus muscle	-23.15	-4.9	23.4
Subscapularis muscle	23.7	-1.21	23.5
Superior glenohumeral ligament	15.09	18.23	16.1
Middle glenohumeral ligament	19.86	1.28	23.4
Inferior glenohumeral ligament	16.29	-12.2	22.27

In table 2 are presented estimates of the angles with the x, y and z axes and of the unitary components of the forces acting on the humeral head (McMahon, 1995).

Table 2. Angles and the unitary forces

The angle and unit force of the element (muscle or ligament)	Angle with the X-axis; Unit component on the X-axis	Angle with the Y-axis; Unit component on the Y-axis	Angle with the Z-axis; Unit component on the Z-axis
Supraspinatus muscle	115°; −0.4226	71.4°; 0.3198	147°; −0.8480
Infraspinatus muscle	145°; −0.8192	60.3°; 0.4965	106.4°; −0.2870
Subscapularis muscle	80°; 0.1736	80°; 0.1736	165.8°; −0.9695
Superior glenohumeral ligament	168°; −0.9744	100°; −0.1736	98.2°; −0.1428
Middle glenohumeral ligament	110°; −0.3420	65°; 0.4226	146.7°; −0.8394
Inferior glenohumeral ligament	130°; −0.6428	45°; 0.7071	107.1°; – 0.2946

The main geometric characteristics, such as length, width, thickness, physiological section and dynamic characteristic, theoretical maximum force, for the muscles and ligaments of the glenohumeral joint and for a man with a height of 1.70 [m] and a weight between 65 and 70 [kg], are presented in table 3, with observations regarding the movement on which they intervene (Howell, 1988; Warner, 1992; Lee, 2000).

Table 3. Geometric characteristics and dynamic

Element (muscle or ligament)	Length [cm]	Width [cm]	Thickness [cm]	Physiological section area [cm^2]	Theoretical maximum force [N]	Observations
Suprasinatus muscle	10-12	2-3	1-1.5	3-4	250-300	Raise the arm to abduction (the first 15-20°)
Infraspinatus muscle	11-13	3-4	1.5-2	4-5	350-450	External rotation, posterior stabilizer
Terres minor muscle	7-9	2-3	1-1.2	2-3	200-250	External rotation, stabilizer
Subscapularis muscle	13-15	4-6	2-3	6-8	500-700	Internal rotation, anterior stabilizer
Deltoideus muscle	15-18	6-8	2-3	12-15	1000-1200	The main muscle of abduction
Teres major muscle	12-14	3-5	2	6-7	450-550	Adduction and internal rotation
Superior glenohumeral ligament	25-35	4-6	1-2	-	150-200	Limits anterior translation to small abductions
Middle glenohumeral ligament	30-40	5-8	2-3	-	200-300	Anterior stability between 45-60° abduction
Inferior glenohumeral ligament	35-50	8-10	3-4	-	350-500	Main anterior stabilizer at high abduction
Coracohumeral ligament	30-40	7-10	2-3	-	400-450	Supports the joint capsule and limits external rotation

If we consider the angular positions with the reference axis system and the geometric position of the insertion points of muscles or ligaments, the projections of the traction forces are determined and presented in table 4. The unit components on the x, y and z axes in table 2 multiplied by the absolute values of the forces in the tendons and ligaments will give the components of the forces on the x, y and z axes. The resultant force acting on the humeral head will be equal to the resultant of these components.

In table 4 are presented the maximum, extreme values of the forces in the tendons and ligaments and the components on the x, y and z axes. The last row of table 4 contains the resultants on the x, y and z axes and the resultant force acting on the humeral head.

Table 4. The components of the forces along the three reference axes

Force from muscle or ligament	Maximum (extreme) [N]	Component on X [N]	Component on Y [N]	Component on Z [N]
Supraspinatus	300	−0.4226 x 300≈-127	0.3198 x 300≈96	−0.8480 x 300≈-254
Infraspinatus	450	−0.8192 x 450≈-369	0.4965 x 450≈223	−0.2870 x 450≈-129
Subscapularis	700	0.1736 x 700≈122	0.1736 x 700≈122	−0.9695 x 700≈-679
Superior gleno-humeral ligament	200	−0.9744x 200≈-195	−0.1736 x 200≈-35	−0.1428x 200≈-29
Middle glenohumeral ligament	300	−0.3420 x 300≈-103	0.4226 x 300≈127	−0.8394 x 300≈-252
Inferior gleno-humeral ligament	500	−0.6428 x 500≈-321	0.7071 x 500≈354	− 0.2946 x 500≈-147
Resultant	2450	-993	887	-1490

RESULTS

The collision of two bodies occurs in a very short time and the impact force is very high and, for this reason, in sports the effect can cause muscle and ligament trauma. The more physically prepared the athlete is and the more sports experience he has, the more he can avoid injuries. From a theoretical point of view, the collision phenomenon starts from the notions of impulse, percussion and the law of conservation of momentum (Brach, 1993; Budescu, 2008). Thus, percussion is defined for a body with the expression:

$$P = m \cdot (v_2 - v_1)$$

where: m – body weight [kg],
v_1, v_2 – the velocities of the body immediately before the collision and, respectively, immediately after the collision.

The multiplication between the mass of the body and its velocity represents the momentum of the body and the average percussion force is calculated with the mathematical relationship:

$$\overline{F}_m = \frac{m \cdot (\overline{v}_2 - \overline{v}_1)}{t_2 - t_1}$$

where: $\Delta t = t_2 - t_1$ represents the time interval in which the collision occurs.

The experiment consisted of video recording an official rugby match, in the national rugby championship, and selecting images in which collisions occurred between two athletes (figure 4).

Fig. 4. The collision of two rugby players (Milburn, 2014)

After the match, the athletes of the two teams who appeared in the video recordings were identified and their weights, in kg, were determined. The video recording was then fragmented into "jpeg" images, obtaining 33 pictures for each second of recording. The measurements of the linear distances covered by the athletes, between two successive images, initially determined in “pixels” were then converted into “meters” using a calibration performed at the beginning of the video recording. Dividing the distance covered between two images by the time interval of 0.030303 seconds, the linear velocity immediately before and after the collision is obtained. In table 5 are presented the obtained values of the distances measured in pixels and meters of the athletes involved in the collision, their masses, the linear velocities then determined by calculation and average percussion force, for all seven valid video sequences captured by our recording device placed in a fixed position at the edge of the rugby field.

Table 5. Values determined based on experiment

Video sequence	Rugby player	m [kg]	Distance [pixeli]	Distance [m]	Velocity [m/s]	Average percussion force
1	1	87	74	0.2442	8.058	23134.541
	2	92	63	0.2079	6.860	20826.980
2	1	81	75	0.2475	8.167	21830.412
	2	78	91	0.3003	9.909	25505.791
3	1	75	93	0.3069	10.127	25064.350
	2	80	81	0.2673	8.8209	23287.199
4	1	87	80	0.2640	8.712	25012.177
	2	80	77	0.2541	8.382	22128.502
5	1	74	98	0.3234	10.672	26061.050
	2	95	63	0.2079	6.860	21506.121
6	1	80	78	0.2574	8.494	22424.182
	2	75	84	0.2772	9.147	22638.847
7	1	84	71	0.2343	7.731	21430.353
	2	78	83	0.2739	9.038	23263.835

In table 5, the average impact force, determined in [N], expresses the intensity exerted between the two bodies during their collision and depends on the variation of the momentum immediately before and after the impact and on the duration of contact between the bodies. There is a linear relationship between the average impact force and mechanical work, through the deformation of the body during the collision. The smaller the deformation, the greater the impact force and the kinetic energy of the body increases.

DISCUSSION

Just as in engineering, where there is a ratio between the overload supported by a shock absorber and the nominal load for which that shock absorber was designed, in the case of the joints of the human locomotor system there is such a ratio, between 2 and 10 times greater than body weight. The factors that determine the overload ratio are the following factors: the type of activity (static, dynamic, impact), the angles of the joint, the muscle tone and the time of application (Goetti, 2021; Viehöfer, 2016, Apreleva, 2000).

From table 4, if the maximum resultant is multiplied by the coefficient 10, a value of the overload force is obtained, a value that can be compared with the values of the average percussion force from table 5. In the graph in figure 5, the forces are represented, in the first column the value of the theoretical maximum force and in the following columns the values of the average percussion forces.

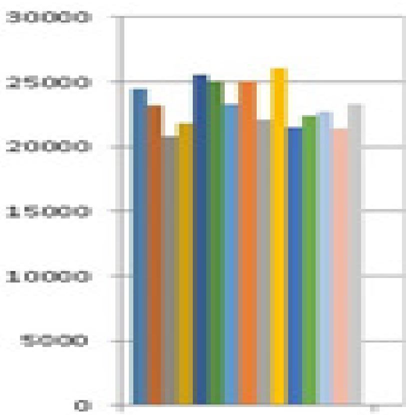

Fig. 5. Maximum theoretical force (first column) and average percussion forces (original graphic by the authors)

Due to the fact that in the calculation of the maximum theoretical force, not all muscles that contribute to the stabilization of the glenohumeral joint were taken into account, it results that the values of the average percussion force, for the analyzed experimental case, do not actually exceed the theoretical value of the joint connection force.

In the case of an athlete who has already had a shoulder dislocation, it may be recommended, in order to prevent the dislocation from recurring, to use a shoulder orthosis for preventive purposes (figure 6).

Fig. 6. Shoulder orthesis
(British Association of Prosthetists and Orthotists, 2023)

Such an orthosis ensures good stability thanks to the three adjustable straps and offers good comfort due to the material's property of regulating temperature at the shoulder level.

CONCLUSIONS

In performance sports, athletes endure mechanical joint overloads due to physical training and experience in dealing with a collision, so joint trauma is often avoided.

The presented biomechanical study offers the possibility of theoretically determining joint connection forces, using the resistive properties of the muscle and ligament tissues that stabilize the analyzed joint.

The experimental research presented in this paper can be extended to other team sports, such as basketball, handball, hockey, etc.

AUTHOR CONTRIBUTIONS

Author 1, author 2, and author 3 contributed to the design of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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EXPLORING THE USE OF ARTIFICIAL INTELLIGENCE IN MOTOR LEARNING IN TENNIS

Dana ION-MUȘAT[1]

ABSTRACT. Sports have always been an important component of human culture due to the combination of neuro-psychic skills, strategic planning, and physical excellence. With the discovery and rapid development of artificial intelligence, its applicability in the sports domain is becoming increasingly evident, and its deep integration is an inevitable trend at this moment. In sports, artificial intelligence combined with data analysis highlights unparalleled opportunities regarding motor learning, outcome prediction, decision-making capabilities, and performance optimization. The integration of methodologies offered by artificial intelligence represents an innovative approach to enhancing athletic performance, which will continue to evolve as a foundation for the technology of sports science. The technique and tactics of tennis have reached a high level due to the evolution of sports equipment, and in response to this phenomenon, coaches have increasingly leveraged the physical training of athletes as it has developed. Following a review of the literature from recent years, we concluded that the data obtained through artificial intelligence provide specific details that can assist coaches and tennis players both in planning training and in the motor learning process. Furthermore, the results obtained through AI in sports analysis, especially for a fast and strategic sport like tennis, have effects on the level of optimization of athletic performance, which implicitly reflects on the competitive results of players. Therefore, this study aims to provide information to tennis coaches and players on how artificial intelligence can be utilized to facilitate motor learning with the objective of optimizing athletic performance. Additionally, we believe that the application of artificial intelligence in the training of tennis players offers specialists insights that can facilitate the adaptation of training methodologies to optimize the motor learning process. By utilizing this information in training, coaches can adapt training methods to meet the demands of modern tennis, thereby improving player outcomes. With technological advancement, the continuous exploration of the motor learning process through artificial intelligence is justified in the attempt to achieve significant or even major progress in optimizing athletic performance in tennis.

Keywords: motor learning, tennis, artificial intelligence

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INTRODUCTION

In the field of sports, the pursuit of improvement and excellence is ever-present. Athletes, coaches, and analysts are constantly seeking innovative methodologies to gain a competitive advantage.

Due to technological advancements in recent years, sports specialists have turned their attention to a variety of mobile electronic devices capable of recording and interpreting a wide range of parameters related to physical exertion (Stoicescu & Stănescu, 2015). Consequently, they have adopted new technologies to enhance game techniques as swiftly as possible. In this dynamic landscape of performance enhancement, the integration of artificial intelligence (AI) emerges as a transformative force, with prospects grounded in the data obtained.

As we know, artificial intelligence has significantly developed in recent years, transforming it into an important tool for optimizing athletic performance across most sports. The interest in all aspects of artificial intelligence has remarkably increased in recent years, and a substantial expansion in its diverse applications, particularly in sports, is anticipated.

Tennis is regarded as an elegant sport that has gradually spread worldwide. Due to the rapid advancements in information technology achieved in recent years, its applicability in the sports domain has become increasingly extensive. Thus, it can be asserted that, in tennis, this information technology plays an essential role. On one hand, it can transform the traditional training model into an innovative one, while on the other hand, it can provide coaches and athletes with significantly more effective training methods. The utilization of data analysis technology in the training of tennis players can furnish coaches with a comprehensive and relevant information base. By collecting, organizing, and analyzing data obtained during training sessions or official matches, the accuracy and efficiency of the training process can be amplified, thereby contributing to the optimization of athletic performance (Siqi Mi, 2025).

TOPIC ADDRESSED

The Impact of advanced technologies on sports performance analysis

Performance analysis in tennis pursues five primary objectives:

1. *Evaluation of tactics:* assessment of game strategies employed.
2. *Evaluation of technique*: analysis of the execution of specific movements in the game.

3. *Displacement analysis*: investigating the efficiency and economy of court movements.

4. *Database creation and modeling*: developing a data repository and predictive performance models.

5. *Provision of educational tools*: offering educational resources for both coaches and athletes (Bozděch, Puda & Grasgruber, 2024).

With the emergence and development of advanced technologies, such as Internet of Things (IoT) connectivity, a significant opportunity has arisen for extensive exploration of motor learning and sports performance analysis.

In recent years, technological advancements and their related applications have exerted a major influence on daily life, particularly within the sporting domain. According to statistics, at the beginning of 2020, over 7.7 billion people and 30 billion devices were interconnected within IoT networks worldwide. Furthermore, it has been demonstrated that by the end of the same year, the number of connected devices had reached 75.44 billion (Rui, 2023).

IoT is defined as "a global network of sensors, devices, and objects that can automatically detect and transmit data, enabling the monitoring, management, and processing of an environment, endowing it with intelligent behavior" (Rui, 2023).

Integration of technology in tennis motor learning

In contemporary tennis, a significant component of athletic mastery is represented by the rapid advancement of technological and scientific progress. Concurrently, there has been a proliferation in the accessibility of specific tennis equipment (Siqi Mi, 2025).

In the training of tennis players, the utilization of information systems, modern communication tools, and AI-based technologies increasingly influences motor learning and athletic performance. Consequently, these factors play a major role in the evolution of training methodologies and the application of efficiency principles specific to tennis. The optimal implementation of current training methodologies in tennis, considering their specific attributes, is a fundamental requirement for enhancing the effectiveness of training programs and optimizing athletic performance (Rui, 2023).

There exists a multitude of typologies of intelligent ecosystems designed for athletes, based on the IoT system. Each of these presents a distinct set of operational characteristics, as illustrated in the diagram below:

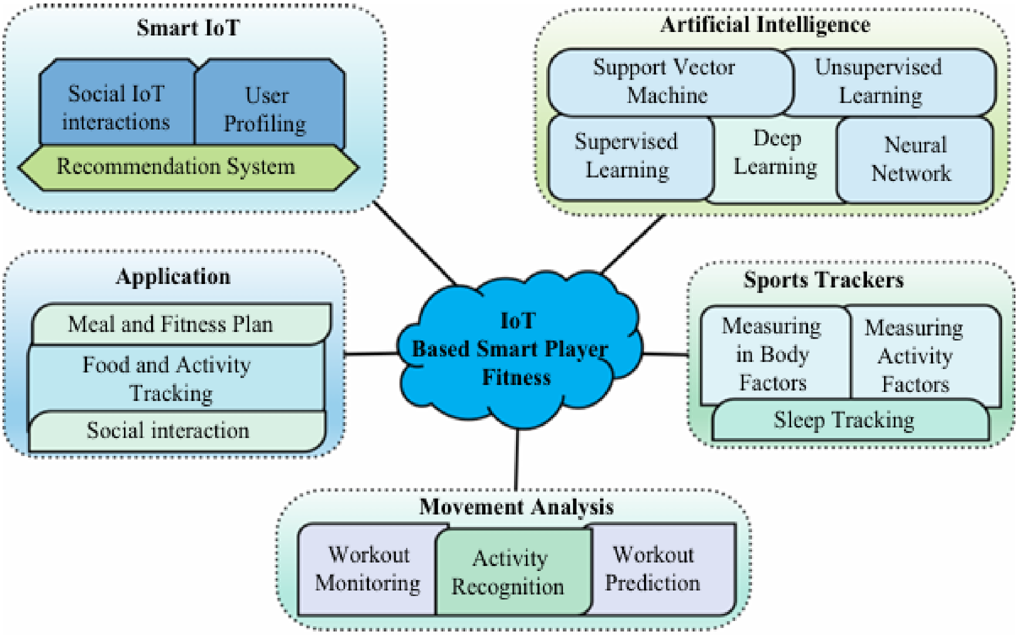

Figure 1. Taxonomies of Intelligent Ecosystems in Sports (Rui, 2023)

TRAINING FREQUENCY AND THE ROLE OF ARTIFICIAL INTELLIGENCE IN MOTOR LEARNING PROCESSES

It has been demonstrated that the frequency of training undertaken by a tennis player has a positive and significant influence on the acquisition of technical skills or proficiencies. Furthermore, the automated assessment of tennis strokes during training sessions plays a crucial role in optimizing athletic performance, preventing injuries, and facilitating rapid recovery post-exertion. To maximize the feedback provided by coaches, it is essential to utilize artificial intelligence. This technology aids in obtaining highly accurate data for evaluating players' technical skills, including stroke mechanics, by employing objective indicators to optimize athletic performance. The objective indicators focus on the following:

- Accuracy/precision of technical executions;
- Consistency/uniformity of performance;
- Execution speed/ball velocity (Bačić & Hume, 2018).

Recent studies have suggested that the development of a tennis training system utilizing artificial intelligence offers a range of high-precision data, which facilitates the creation of a personalized training program tailored to the specific characteristics of each player. Furthermore, the utilization of new AI technologies in technical training within tennis indicates a significant improvement compared to traditional technical preparation, by refining fundamental motor patterns that reduce the risk of injuries and establish a solid foundation for the development of tennis-specific skills and competencies. Additionally, the acquisition of specific motor skills is achieved more easily and rapidly through AI-assisted training systems. Moreover, both cognitive capacity development and the transfer of motor skills are facilitated with ease through virtual reality technologies. Virtual reality technology is particularly beneficial for players' mental fortitude and tactical approach to matches, as it provides athletes with clearer visualization and the practice of responses to various game situations without the physical strain and stress associated with current official matches (Liu et al., 2024).

Integration of New Technologies in Tennis

1. *Virtual Reality (VR) Technology* serves as a connection point between human beings and computers, distinguished by the following fundamental characteristics:

- Immersiveness
- Interactivity
- Conceptualization

Virtual Reality Technology is presented as an optimal integration of information technology, simulation technology, multimedia technology, artificial intelligence, microelectronics technology, detection technology (via sensors), and more. Additionally, VR can create an adaptable multidimensional informational space, with extremely vast application prospects, simulating human sensory functions (sight, hearing, touch). This capability allows for the engagement of an individual in a computer-generated virtual environment that interacts with them in real time through language, gestures, and other means. In tennis, the implementation of VR offers athletes a different approach to training, significantly enhancing the effectiveness of training sessions and the safety of players (Siqi Mi, 2025).

Researchers have found that in tennis, athletes can practice in scenario-specific contexts akin to official matches, even when these are facilitated by virtual reality. These virtual scenarios assist players in adopting varying levels of motor skills that can be utilized in competitions, thereby enhancing their sports performance precisely during critical moments of the game, ultimately aiding them in securing victories. Another advantage of training within a virtual reality environment is that it provides a safe practice framework, significantly contributing to injury prevention (Liu et al., 2024).

According to Bodemer (2023), the VR environment offers a context where the repetition of tennis-specific exercises considerably reduces the physical strain experienced from conventional training methods.

2. The *wearable devices* operate based on sensors applied to the human body, smartwatches, or, in this case, sensors affixed to tennis rackets, which transmit information regarding bodily activity or the velocity imparted to the tennis ball to other electronic devices via a wireless network. The advantages of these devices include their compact size, extensive multifunctionality, and low energy consumption, among others. The utilization of smart sensors facilitates real-time monitoring of physical condition, measuring biomechanical parameters and functional movements of players. Consequently, coaches gain access to detailed and precise data aimed at optimizing training effects and, implicitly, competitive sports outcomes (Siqi Mi, 2025).

3. *Smart ball launchers* are robotic equipment with advanced programming capabilities for speed, spin, and direction. These devices can significantly influence motor learning in tennis and can be adapted to all levels of training. Moreover, smart launchers can also be employed in the tactical preparation of players due to their functions (direction, varying effects, and speed of the tennis ball).

4. *The machine learning* occurs through algorithms that process data from sensors worn by players during training. This significantly enhances the refinement of technical skills, including shot execution techniques and movement actions specific to the game of tennis. Automated learning provides coaches with the ability to improve players' techniques through personalized training programs aimed at optimizing tennis-specific technical skills (Perri et al., 2022).

In tennis, personalized learning plays a crucial role in acquiring and developing specific technical skills. Through individualized learning, athletes can exhibit enhanced capabilities regarding their understanding and refinement of specific motor skills, ultimately aimed at optimizing athletic performance (Koopman et al., 2020).

Additionally, experts suggest that another interpretation of personalized learning involves combining learning tasks with complementary, non-specific tennis activities, thereby facilitating the acquisition process of technical skills.

5. *Action Recognition Systems* can be realized through the integration of three distinct algorithmic modules:

- Posture recognition model (Open Pose-bm);
- Skeletal action recognition network (AA-GCN - Attention-Augmented Graph Convolutional Network);
- CTFC-GCN Structure (Channel Topology Feature Fusion Graph Convolutional Network).

An example of a comprehensive skeletal action recognition process through the integration of semantic information is explained and illustrated below (see Fig. 2).

1. *System Input*: The model receives an RGB video stream as input.
2. *Posture Estimation*: The Open Pose-bm algorithm is applied to perform human posture estimation; this step generates a lightweight JSON file containing the total number of frames and the 2D coordinates of 13 joint landmarks for each frame.
3. *Classification*: Based on a priori information, the connectivity relationship between joints (the skeletal graph) is constructed. The dataset is then divided into training-validation sets and input into the AA-GCN skeletal network for action recognition.

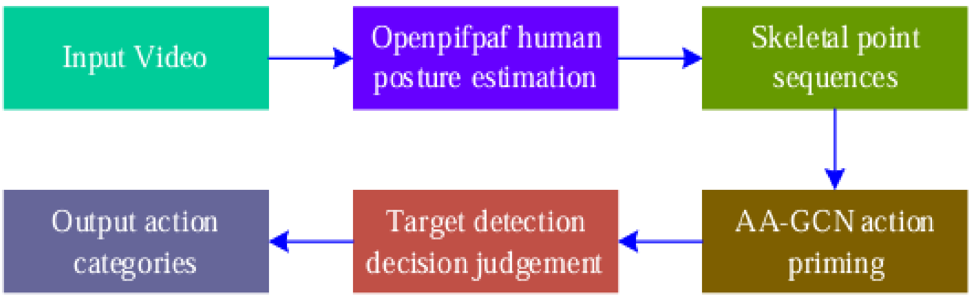

Figure 2. Human action recognition process (Siqi Mi, 2025)

In Figure 3, you will find a model for the detection and analysis of the biomechanics of specific actions in the game of tennis.

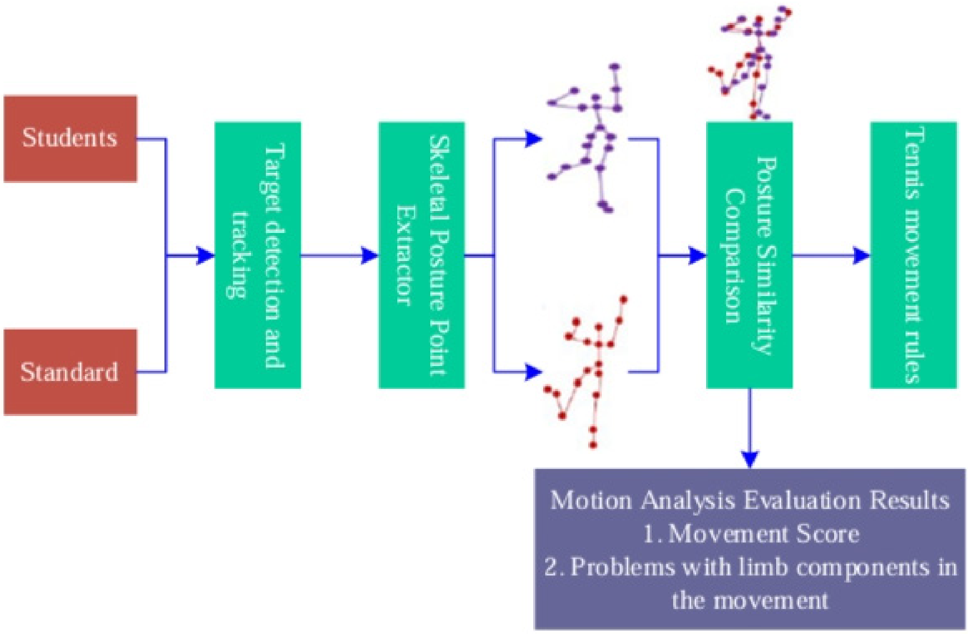

Figure 3. Overall design of tennis action recognition and analysis system

In tennis, sport-specific motor actions can be subjected to methodological analysis through two distinct paradigms:

1. - the motor gesture as a *continuous-time sequence*: specifically, the body joints execute a spatial displacement; consequently, the velocity data of these trajectory points provide a comprehensive description of the movement dynamics;

2. - the execution of a technical skill (e.g. the serve) as *a motor act*: defined by the force exerted at the radiocarpal joint (wrist) and subsequent postural transitions; in this framework, the recognition of the motion segment is achieved through the continuous assessment of body posture (Ruan & Zhang, 2022).

Researchers assert that these innovative technologies possess the capacity to facilitate specific and beneficial modifications within training regimens, grounded in measured performance and the identification of technical deficiencies throughout athletes' preparation sessions. They emphasize the need for athletic progress to be monitored with the intention of motivating players by highlighting improvements made over time.

Supporting this idea, Taghavi (2019) stated that sensors utilized in training, such as smartwatches, significantly contribute to the collection of data regarding technical skills, including the detection of tennis strokes, leading to a heightened level of performance.

Through the systematic acquisition, aggregation, and storage of performance indicators, coaches and athletes are afforded the opportunity to understand the level of play in real-time and can enhance specific technical skills to optimize athletic performance.

It is important to note that the accuracy of visual recognition algorithms largely depends on external conditions, such as lighting or game speed, and the integration of these technologies into the educational process of sports requires a well-defined methodological framework (Prăjescu & Abalașei, 2025).

CONCLUSION

The identification of technologies related to artificial intelligence underscores the dynamic and evolving nature of applications developed with its assistance, particularly in tennis. As the sport continues to progress alongside technological advancements, these analytical systems have the potential to provide even more data in the future.

Current research on sports performance analysis and optimization will continue to furnish tennis players and coaches with valuable insights based on concrete data, thereby aiding in the personalization and efficiency of training methods. Advancements in machine learning and neural networks will enhance the predictive capacity regarding athletic performance in tennis, facilitating more precise and effective training regimens. The utilization of computer vision and deep learning technologies will lead to innovative solutions for real-time monitoring and feedback, transforming traditional training approaches and methods of game analysis. Consequently, players and coaches will have the opportunity to access information during matches, which may optimize game strategy and performance.

However, the advantages offered by artificial intelligence come with certain inherent limitations. Training conducted solely through technology may reduce an athlete's self-regulation capacity and hinder the development of intuitive skills. Additionally, the high costs associated with these devices may restrict their usage.

Ongoing research into the relationship between artificial intelligence and motor learning in tennis will support interdisciplinary collaborations and the development of new learning systems for the sport. This will create new opportunities for research and innovation, contributing, to some extent, to the evolution of tennis and the history of sports.

AUTHOR CONTRIBUTIONS

The author has made a substantial, direct, and intellectual contribution to the work and approved it for publication.

CONFLICT OF INTEREST

The author declare no conflicts of interest.

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INFLUENCE OF GENDER ON MOTRICITY IN ADOLESCENTS

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ABSTRACT. ***Introduction***: Educating motricity during adolescence is of great relevance, as it determines an improvement in physical effort capacity, experiencing new motor sensations, and enriching knowledge. ***Objective***: The study aimed to evaluate the motor capacity of a group of 139 adolescents (78 girls and 61 boys), with a mean age of 16.5 ± 0.5 years, by conducting a series of physical trials to identify possible gender-based differences. ***Methods***: We applied six physical trials to assess the level of motor performance indicators: standing long jump, push-ups, torso raises from the supine position in 30 seconds, torso extensions from the prone position on a gymnastics bench in 30 seconds, shuttle run – 5 × 10 m, and resistance running (800 m for girls and 1000 m for boys). ***Results***: Data analysis has shown a significance threshold (Sig) < 0.05 for all six dependent variables included in the research. Significant gender differences were noted in upper limb power (mean difference = 2.760), abdominal muscle power (mean difference = 3.658), and back muscle power (mean difference = 2.659). ***Conclusion***: The study has found statistically significant differences between girls and boys in terms of motricity during adolescence, and the information obtained may serve as a valuable point of reference for future research.

Keywords: motricity; physical trials; adolescents; differences; gender.

INTRODUCTION

Exercise capacity, or human biological potential, is assessed according to the level of manifestation of motor abilities, skills, and competencies. It is well known that fitness has a significant influence on motor performance, which is

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particularly important during adolescence. Indeed, in addition to enhancing exercise capacity, young people have the opportunity to experience new motor sensations and improve their knowledge regarding this area.

The essential aspects to consider in order to achieve the desired effects on motor performance include an accurate dosage of exercises throughout a routine, the observance of the required intensity and workload, and the adjustment of exercises to the individual characteristics of adolescents (Pinho et al., 2024).

We can also enhance the motor capacity of adolescents by implementing a HIIT-based exercise routine during school Physical Education classes, as proven by a study that Jovanovic et al. (2024) carried out in Serbia. Similarly, it was reported that strength and endurance exercises performed during school Physical Education classes led to higher motor performances among Spanish teenagers (Pérez-Ramírez et al., 2024).

Physical activities or exercises implemented during school classes are the most effective and, therefore, should be given more time in the daily schedules of teenagers. When conducted under the supervision of a qualified instructor, physical activity improves motor capacity, leads to the development of altruistic and prosocial behaviours among young people, and highlights the significant role of Physical Education teachers, who can thus become positive role models (Flores-Piñero et al., 2024).

In another study, Bento et al. (2022) underlined the importance of moderate to vigorous physical exercise in better motor performance. The authors recommended regular exercise as part of young people's lifestyles. It is also worth noting the study conducted by Pryimakov et al. (2023), which optimised the motor capacity of Ukrainian adolescents by including CrossFit exercises within Physical Education classes.

Faigenbaum et al. (2023) also explored the need to improve motor capacity among teenagers. They investigated this topic in the context of mitigating the risk of developing various diseases associated with sedentary behaviour. Moreover, Farías-Valenzuela et al. (2022) examined the impact of physical exercise on motor capacity among adolescents with intellectual disabilities. They found that physical exercise, in addition to increasing exercise capacity in individuals with such conditions, also had other beneficial effects that contributed to improving their quality of life.

In another study conducted by Wang (2021), data showed that boys displayed higher levels of motor capacity than girls during adolescence; this fact was proven by the results obtained in school physical fitness tests (standing long jump, sprint running, resistance running, and abdominal muscle strength).

We aimed to assess the motor capacity of 139 adolescents (78 girls and 61 boys), aged 16.5 ± 0.5 years, using physical trials designed to identify potential gender-based differences.

There is gender-based differences regarding the level of motor indices.

MATERIAL AND METHODS

The study was conducted in September 2024 at "Emil Racoviță National College" in Iași. The research participants, 139 adolescents (78 girls and 61 boys), aged 16.5 ± 0.5 years, were students at this college.

The evaluation activities were scheduled over six days and were carried out by the students both in the specially equipped gymnasium and on the school's sports field, between 10:00 and 12:00. To avoid interference effects, the tests were organised as follows

- Day 1 – Standing long jump
- Day 2 – Push-ups
- Day 3 – Torso raises from the supine position
- Day 4 – Trunk extensions
- Day 5 – Sprint running
- Day 6 – Resistance running

Participants

Before the study began, both students and their legal guardians signed a voluntary participation agreement.

The study adheres to all ethical and deontological standards of scientific research, as outlined in the *Declaration of Helsinki*, and was approved by the Scientific Research Ethics Committee of "Alexandru Ioan Cuza" University of Iași, Faculty of Physical Education and Sports, under approval number 27/30.04.2024.

Procedure

The level of motor capacity (exercise capacity) of the adolescents participating in the research was assessed through physical tests designed to evaluate the strength of the main muscle groups, running speed, and cardiorespiratory endurance, as follows:

a. Lower limb strength – Standing long jump (cm):

– Standing with feet apart behind a line, the subject bends their knees while swinging their arms backwards, then propels the trunk forward, performing a powerful leg impulse and jumping forward, accompanied by an arm swing. Landing is made in a squat position.

The jump distance was measured with a measuring tape, recording the number of centimetres from the starting line to the heels.

Each subject performed two jumps, and the best result was recorded.

b. Upper limb strength – Push-ups:

– From the prone position, on hands and toes, the subject bends the arms at the elbow joint and returns to the starting position.

The number of correctly executed repetitions was recorded.

c. Abdominal muscle strength – Torso raises from the supine position for 30 seconds:

– From the supine position, hands placed behind the neck, knees bent at 90°, feet on the ground: torso raise followed by return to the supine position.

The number of repetitions performed within the allotted time was recorded.

d. Back muscle strength – Trunk extensions from the prone position on a bench for 30 seconds:

– From the prone position, pelvis supported on a transverse gym bench, hands behind the neck, legs fixed: trunk extension and lowering until reaching bench level.

The number of extensions performed within the time limit was recorded.

e. Running speed – 5 × 10 m shuttle run:

– The participant stands behind the starting line. At the signal, they run back and forth as fast as possible, crossing the opposite line (10 m away) with both feet each time.

The test was performed with a stopwatch, and the time was recorded in seconds and hundredths of a second.

f. Cardiorespiratory endurance – Resistance running (800 m for girls; 1000 m for boys):

– Standing start, running together over the indicated distance.

The time obtained by each participant was recorded in minutes and seconds.

Statistical analysis

The data obtained from the applied tests were entered into the IBM SPSS Statistics 20 software for processing and analysis using several statistical tools, as follows:

- The Kolmogorov-Smirnov test, used to verify the normality of the data distribution in the study, as this test is recommended for the size of the evaluated group (Table 1).
- The Independent *Samples t*-Test, used to identify possible differences between the mean values obtained by boys compared to girls concerning motor performance indices, as well as to determine the statistical significance of these values (Table 2).
- Welch's test, which was considered when the condition of homogeneity of variances was not met.

RESULTS

Table 1. Results of the **Kolmogorov-Smirnov** test for motor indices

Variables	Gender	Statistic	df	Sig.
Lower limb strength	Male	.083	61	**.200***
	Female	.081	78	**.200***
Abdominal strength	Male	.134	61	.008
	Female	.175	78	.000
Back strength	Male	.136	61	.007
	Female	.152	78	.000
Upper limb strength	Male	.308	61	.000
	Female	.169	78	.000
Movement speed	Male	.224	61	.000
	Female	.133	78	.002
Endurance	Male	.151	61	.001
	Female	.097	78	**.064**

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction
Sources: Ivaşcu & Ungurean (2025).

The results of the Kolmogorov-Smirnov test for verifying the normality of the data distribution show that the "Lower limb strength" variable has a normal distribution ($p > 0.05$) for both genders ($p = 0.200$). In contrast, the variable "Endurance" has a normal distribution only in the group of girls ($p = 0.064$). The other variables deviate from the normal distribution in both groups of subjects.

Table 2. Independent *Samples t*-Test results

Variable		Levene's Test for Equality of Variances F	Sig.	t-test for Equality of Means t	df	Sig. 2-tailed	Mean Diff.	Std. Error Diff.	95% Confidence Interval of the Difference Lower	Upper
Lower limb strength	Equal variances assumed	16.882	.000	18.065	137	.000	.295	.016	.262	.327
	Equal variances not assumed			19.340	122.747	.000	.295	.015	.264	.325
Abdominal strength	Equal variances assumed	2.975	.087	9.438	137	.000	3.658	.388	2.891	4.424
	Equal variances not assumed			9.800	136.401	.000	3.658	.373	2.920	4.396
Back strength	Equal variances assumed	.073	.787	7.002	137	.000	2.659	.380	1.908	3.410
	Equal variances not assumed			7.094	134.299	.000	2.659	.375	1.918	3.401
Upper limb strength	Equal variances assumed	31.774	.000	13.222	137	.000	2.760	.209	2.347	3.173
	Equal variances not assumed			14.202	120.404	.000	2.760	.194	2.375	3.145
Movement speed	Equal variances assumed	165.824	.000	-7.323	137	.000	-1.282	.1750	-1.628	-.9359
	Equal variances not assumed			-8.269	78.802	.000	-1.282	.1550	-1.590	-.9734
Endurance	Equal variances assumed	45.691	.000	5.383	137	.000	.0791	.0147	.0500	.1081
	Equal variances not assumed			5.827	114.453	.000	.0791	.0135	.0522	.1060

Sources: Ivaşcu & Ungurean (2025).

The analysis of the data obtained shows that the significance threshold (Sig.) is < 0.05, which highlights the gender-based differences in the analysed motor performance indices.

The results of the Student's *t*-test for the following variables are presented below:

• Abdominal strength – the variances of this variable in the two groups are equal ($p = 0.087$); the means of the variable in the two groups differ significantly (MA = 23.61 for boys and MA = 19.95 for girls); $t(137) = 9.438$, $p < 0.05$, mean difference = 3.658. The difference between the means of boys and girls falls within the interval 2.891–4.424, with a 95% confidence level.

• Back strength – the variances are equal ($p = 0.787$); the mean values differ between genders (MA = 25.67 for boys and MA = 23.01 for girls); $t(137) = 7.002$, $p < 0.05$, mean difference = 2.659. The difference between the means of boys and girls ranges between 1.908 and 3.410, with a 95% confidence level.

According to Levene's test, the variances of certain variables in the two groups are not equal ($p = 0.000$). Therefore, for these variables, the results of Welch's test were considered, as it is recommended in such situations.

The variables failing to meet the condition of equal variances are as follows:

• Lower limb strength – variances are not equal ($p < 0.05$); the mean values of the variable in the two groups differ slightly (MA = 1.87 for boys and MA = 1.58 for girls); $t(122.74) = 19.340$, $p < 0.05$, mean difference = 0.295. The difference between the means of boys and girls ranges within the interval 0.264–0.325, with a 95% confidence level.

• Upper limb strength – gender-based variances are not equal ($p < 0.05$); the mean values differ significantly (MA = 9.31 for boys and MA = 6.55 for girls); $t(120.404) = 14.202$, $p < 0.05$, mean difference = 2.760. The difference between the means of boys and girls lies within the interval 2.375–3.145, with a 95% confidence level.

• Running speed – variances in the two groups are not equal ($p < 0.05$); the mean values differ slightly (MA = 19.3985 for boys and MA = 20.6806 for girls); $t(78.802) = -8.269$, $p < 0.05$, mean difference = –1.2821. The difference between the means of boys and girls ranges within the interval -1.5907 to –0.97348, with a 95% confidence level.

• Endurance – gender-based variances are not equal ($p < 0.05$); the mean values in the two groups differ slightly (MA = 4.5148 for boys and MA = 4.4356 for girls); $t(114.453) = 5.827$, $p < 0.05$, mean difference = 0.07911. The difference between the means of boys and girls falls within the interval 0.05222–0.10601, with a 95% confidence level.

DISCUSSION

In this study, the assessment of adolescents' motor capacity (MC) level revealed differences between boys and girls, which are attributed to both gender-specific characteristics at the age of 16.5 ± 0.5 years and the degree of interest in physical exercise (PE).

In this context, it is worth highlighting the study conducted in Spain by Aixa-Requena et al. (2025), which also reported gender-based differences in tests assessing several components of MC, such as the 20-meter shuttle run, as a measure of endurance. In addition, a recent study by Sheng et al. (2025) has found higher scores among boys in motor performance indices. The authors explain that girls obtained considerably lower results than boys in physical trials, on the one hand due to gender-specific traits and, on the other hand, to their lower motivation and reluctance to step out of their comfort zone.

Several schools in Switzerland implemented a project that allowed students to use gyms and sports equipment whenever their schedule allowed it, as reported in a study by Ferrari et al. (2025), with the goal of improving the MC of teenagers. Their research, aimed at evaluating adolescents' MC to point out the effects of this initiative, revealed gender differences in motor performance levels, with higher scores recorded among boys. This outcome was justified by the fact that boys took advantage of this opportunity far more than girls, thereby improving their exercise capacity.

Gender-based differences in MC among adolescents were also reported by the study carried out by Mayolas-Pi et al. (2025), which reported lower scores among girls compared to boys in physical trials.

Similar findings were obtained in Portugal by Moreira et al. (2024), who noted that boys scored higher than girls in motor performance indices following physical trials. According to the authors, this is due to the greater time invested by boys (5–7 days per week) in Physical Education, whereas girls did not exceed 2–3 sessions per week. Furthermore, girls were not satisfied with the content of school Physical Education curricula, arguing that the activities did not match their interests.

Moreover, Fernández-Galván et al. (2024), in a study conducted in Spain, found that girls outperformed boys in the sit-and-reach flexibility test. Boys, however, scored higher in the standing long jump and sprint tests; these findings are similar to those of the present study. The fact that adolescent girls are more prone to sedentary behaviour may be one of the factors accounting for gender differences in motor performance indices (Melguizo–Ibáñez et al., 2023). Also carried out in Spain, this study highlights the need to adapt physical education programs to students' preferences and characteristics as a means of encouraging participation and increasing adolescents' interest in physical exercise overall.

In China, the research study by Liu et al. (2023) reported that boys of normal weight achieved higher scores than girls within the same category in physical trials (standing long jump, sprint, pull-ups, and resistance running over 1000 m). Nonetheless, girls outperformed boys in the sit-and-reach flexibility test. The authors also emphasised that underweight girls obtained better motor test results compared to underweight boys.

Gender differences in MC were also identified by Escolar-Llamazares et al. (2023), who noted that boys were more physically active, primarily to lose weight, whereas adolescent girls tended to rely less on exercise and more on dietary control to maintain their desired weight. Although statistics indicate that teenage participation in physical activity has improved in China, interest levels still differ by gender (He et al., 2022). Girls tend to be less enthusiastic about the effects of physical exercise on their bodies. At the same time, boys proved greater consistency and determination in maintaining their exercise habits, primarily to improve their physical appearance, as noted by the authors.

Yuan et al. (2022) investigated the effects of physical exercise (PE) on specific non-cognitive abilities. They reported no significant differences between boys and girls regarding the time allocated to PE or the values obtained in several tests that assessed motor capacity (MC). Furthermore, unlike boys, girls consider PE an excellent opportunity to adjust to the school schedule, considering its role in encouraging interpersonal relationships and improving physical fitness. In addition, Pan et al. (2022) pointed out, in their study on the association between PE and the time devoted to other extracurricular activities, that boys are more prone to engaging in various physical exercises more often than girls. The interest in physical appearance, developed through specially designed exercise routines, falls within boys' sphere of interest, as they view this activity as a means of combating stress and enhancing their MC levels.

Vásquez-Gómez et al. (2021) conducted a study in Chile to assess the cardiorespiratory capacity of adolescents, including both males and females. Boys scored higher than girls, as they covered a longer distance in the endurance test, thus demonstrating a superior exercise capacity. Along the same line, we note the study by Luque-Casado et al. (2021), which pinpointed gender-based differences in the level of motor performance indices, which were again higher among boys. According to the study's findings, boys exhibit greater interest and motivation toward engaging in PE, factors that contribute to their better performance compared with girls in physical tests.

In the study conducted by Mascherini et al. (2022) on a sample of 1,915 Italian adolescents, aimed at identifying the level of manifestation of motor abilities (speed running, cardiorespiratory endurance, agility, limb strength, and joint mobility), gender differences were likewise highlighted; they were mainly attributed to biological sex characteristics. Compared to the average values recorded among European adolescents of the same age, Italian teenagers achieved better results in speed and strength trials but lower results in endurance and flexibility assessments.

Kandrac et al. (2021) carried out a study to determine the level of MC among Slovak adolescents. Based on the results obtained in several physical trials (resistance running, standing long jump, push-ups, joint mobility, and running speed), it was found that boys scored better than girls in endurance, muscle strength, and sprint performance.

In another study, Ballarin et al. (2022) evaluated muscle strength and cardiorespiratory endurance among Italian adolescents. The results revealed differences between girls and boys in both strength and endurance indices.

CONCLUSIONS

The results of the physical trials we administered demonstrate that, during adolescence, gender influences motor capacity (MC), as statistically significant differences were found between boys and girls in terms of motor performance indices.

Studies have shown that, in general, boys outperform girls of the same age in both exercise capacity and physical development. The value of motor performance indices is higher in boys, partly due to gender-specific characteristics, partly because they tend to engage more actively in physical exercise, primarily to improve their physical appearance. On the contrary, girls often prefer to follow various diets, even at the risk of negatively affecting their general health.

At the same time, it is essential to raise awareness among adolescents regarding the beneficial effects of improving MC on the human body, with the ultimate goal of reducing gender disparities.

Given that the enhancement of MC among young people is a current and relevant topic, the information and data obtained through this study may serve as a valuable reference point for future research.

AUTHOR CONTRIBUTIONS

Both authors contributed equally. Both authors were involved in the conceptualisation, design, and application of the working methodology, as well as the software development, validation, writing, and preparation of the original draft. Both authors have read and agreed to the published version of the manuscript.

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EVALUATION OF MOTOR ABILITIES OF PRIMARY SCHOOL PUPILS IN THE CONTEXT OF HYBRID LEARNING THROUGH PHYSICAL EDUCATION

Adrian Constantin LUNGU[1], Elena VIZITIU LAKHDARI[2*]

ABSTRACT. ***Introduction***: Physical education represents the formation and harmonious development of primary school pupils, contributing both to their physical health and to their adaptation to the requirements of modern education. In the context of hybrid learning, the application of motor tests provides a clear picture of children's developmental levels and the effectiveness of the teaching methods used. ***Hypothesis***: It is assumed that integrating physical education tools adapted to the hybrid learning context significantly contributes to maintaining and improving the motor skills of primary school pupils. ***Research aim****:* The aim of this study is to highlight the role of physical education in assessing and developing pupils' motor abilities within a hybrid learning process. ***Objectives of the study****:* To apply standardized motor tests: the 10x5 m shuttle run, trunk lifts, static balance test, upper limb strength test, and joint mobility test. To analyze the obtained results to identify the current level of physical abilities. To formulate methodological recommendations for improving physical education activities in a hybrid system. ***Results****:* The results confirm the importance of integrating varied and adapted methods within physical education, even under hybrid learning conditions, demonstrating that pupils can maintain and develop basic motor skills when the educational process is well-structured and oriented toward their specific needs.

Keywords: motor abilities, primary school pupils, hybrid learning, physical education

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INTRODUCTION

Physical education is a component of the educational process, contributing to the harmonious development of children starting in primary school. Through motor activities, students develop both basic motor skills (strength, speed, endurance, coordination, balance) and social abilities such as cooperation, discipline, and team spirit. Recent changes in the educational system, driven by the shift to hybrid learning formats, have necessitated the adaptation of teaching and assessment methods in the field of physical education as well. The implementation of hybrid pedagogical models helps overcome the limitations of traditional approaches and improves learning outcomes in physical education (Shen at al., 2022). In the context of combining face-to-face activities with online sessions, teachers face challenges in maintaining an optimal level of physical activity, making adapted tools necessary to monitor student progress. Hybrid digital learning has proven to be an innovative approach for developing motor performance in physical education classes (Hidayatullah et al., 2024). Recent studies confirm the effectiveness of hybrid learning in developing motor skills and self-learning abilities. Author (Chen, 2025) highlighted that hybrid environments contribute to increased physical activity, improved cognitive performance, and reduced stress. Another study by (Moon et al., 2023) emphasizes that blended learning offers flexibility while retaining the benefits of direct interaction. Additionally, (Gonzalez-Villora et al., 2019) show that the hybridization of pedagogical models supports the development of both motor and psychosocial skills, if teachers are adequately trained. The integration of gasification into the blended learning process stimulates motivation and knowledge retention (Ghorbel et al., 2025), while the use of direct video feedback has proven effective in improving motor techniques in primary school students (Kyriakidis et al., 2022). The research conducted by (Golikova et al., 2023) supports the idea that the digitalization of physical education allows for an optimal combination of practical instruction and online theoretical resources through models such as the “flipped classroom” or “station rotation.” The investigation by (Carr, 2021) highlights the role of hybrid learning in students’ social and emotional development, emphasizing their active engagement in the educational process. Likewise, the analysis conducted by (Mohammed Fahid Al-Matiry, 2020) shows that blended learning methods significantly improved motor performance in children across various athletic disciplines. In this context, the present study aims to analyze the role of physical education in developing the motor skills of primary school students by applying standardized tests and interpreting the obtained results, with the goal of optimizing the hybrid educational process.

MATERIAL AND METHODS

Participants

The study was conducted on primary school students in the 4th grade, under the guidance of teacher Lungu Adrian. Students were selected based on the following inclusion criteria: enrollment in the 4th grade during the 2024 school year; adequate general physical fitness, with no medical conditions limiting participation in physical activities; parental consent for participation in the assessment; and active attendance in physical education activities conducted in a hybrid format.

Procedure

The experiment was conducted during Module IV of the 2024–2025 school year at the “Vasile Gherasim” Technological High School in Marginea, within physical education classes. The activities were organized in a hybrid format, combining face-to-face lessons in the gym with the control group and online exercises, also conducted in the gym, with the experimental group. Both the initial and final assessments were carried out for the experimental group as well as the control group. Each student underwent a set of standardized motor tests, applied in the following order: Shuttle Run 10x5 m (speed in the resistance regime), Sit-ups in 30 seconds (abdominal strength); Static Balance Test (ability to maintain position); Upper Limb Strength Test – Push-ups; Joint Mobility Test (flexibility and range of motion).

Experimental Physical Education Program – 7 Weeks (Hybrid System)

General Objectives: Improve speed and endurance. Develop abdominal and upper limb strength. Maintain and stimulate static balance. Increase joint mobility. Adapt activities for hybrid learning. Weekly Structure: Face-to-face lessons: 2 sessions per week (gym). Online lessons (simulated in the gym as if at home): 1–2 sessions per week (video platform, demonstration exercises, interactive activities). Week 1 – Introduction and Initial Assessment. Face-to-face: General warm-up: 5 min light jogging, joint mobility exercises. Initial tests: Shuttle Run 10x5 m, sit-ups, push-ups, static balance, joint mobility. Simple motor games for familiarization. Online: Mobility exercises: shoulders, hips, ankles. Video tutorial: correct technique for sit-ups and push-ups. Week 2 – Speed and Endurance. Face-to-face: Warm-up: 5 min jogging, mobility exercises. Shuttle Run 10x5 m: 3 sets with 2 min rest between sets. Reaction games and short sprints. Online: Gym circuit: running in place, knee-to-chest jumps, lateral jumps. Breathing and coordination exercises. Week 3 – Abdominal Strength. Face-to-face:

Warm-up: 5 min mobility and dynamic stretches. Sit-ups: 3 sets of 20–25 seconds, 1 min rest. Plank and simple variations (side plank). Week 3 – Online: Abdominal exercises via video: knee-to-chest raises, bicycle crunches, plank 15–30 sec. Interactive games to maintain attention and motivation. Week 4 – Upper Limb Strength. Face-to-face: Warm-up: shoulder and arm mobility, 5 min. Modified push-ups (knees on the floor) and standard push-ups: 3 sets. Exercises with a ball or resistance band for arms. Online: Bodyweight exercises: wall push-ups, arm raises, exercises with water bottles. Video guidance on correct posture. Week 5 – Balance and Coordination. Face-to-face: Warm-up: walking on toes and heels, 5 min. Static balance test: 3 sets of 30 sec. Exercises on a straight line or over small obstacles Online: Home balance exercises: standing on one leg, lateral swaying. Coordination and reaction games: video with visual and auditory cues. Week 6 – Joint Mobility and Flexibility. Face-to-face: Warm-up: 5 min dynamic exercises. Global stretching: shoulders, back, hips, calves. Active and passive flexibility exercises. Online: Video tutorials for stretching: each muscle group, hold 30–45 sec. Breathing and relaxation exercises. Week 7 – Final Assessment and Consolidation. Face-to-face: Repetition of initial tests: Shuttle Run 10x5 m, sit-ups, push-ups, static balance, joint mobility. Motor games for consolidation and progress assessment. Online: Exercise recap: mobility, balance, strength, coordination. Individual feedback and personalized recommendations. Methodological Note: All online exercises are adapted to the limited space available at students' homes. Common materials are used: stopwatch, balls, water bottles, mats. Progress is monitored by comparing the results of the initial and final tests.

Materials

Standard sports equipment: markings for shuttle runs, digital stopwatches. Materials for hybrid learning: 3 m mat used for students to perform exercises online, simulating a home environment; demonstration and monitoring videos. Individual evaluation sheets: for recording initial and final values for each test.

Data analysis

The obtained values were compiled and analyzed for each test, comparing the performance of the experimental group with that of the control group. For each test, the following were calculated: mean ($\bar{x}$) for the initial and final tests; mean difference (D = FT − IT); standard deviation (σ); coefficient of variation (Cv%); and maximum and minimum values. The results were interpreted in the context of maintaining and developing students' motor skills under hybrid learning conditions. The analysis allowed for the identification of motor components that respond positively to the adapted activities.

RESULTS

The collected data were analyzed to identify relevant differences and trends between the control group, which worked face-to-face, and the experimental group, which worked online.

In Fig. 1, the 10×5 m shuttle run test shows an improvement in average speed, with the initial mean time being 16.66 seconds and the final mean time 16.44 seconds, representing a difference of 0.23 seconds. However, the post-test coefficient of variation of 47.48% indicates a high variability among students, suggesting that the effect of the online program was not uniform. The maximum and minimum values were similar between the initial test (18.41 – 13.97 seconds) and the final test (18.39 – 13.94 seconds).

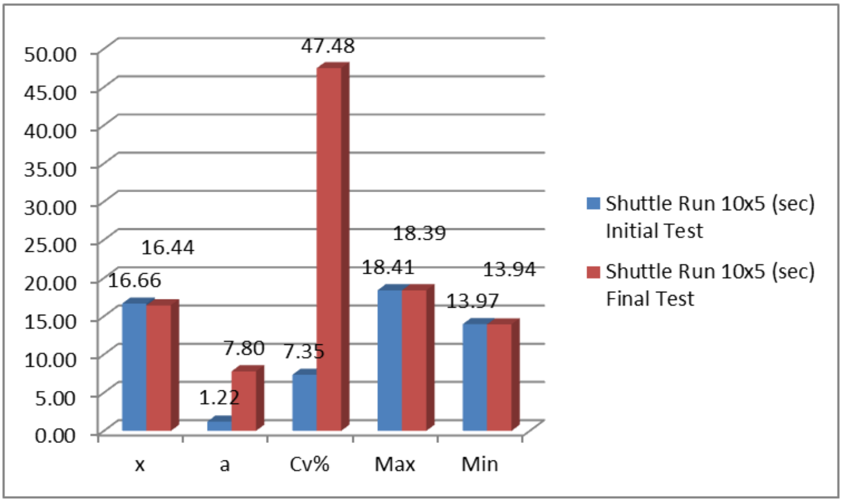

Fig. 1. Progress of students in the face-to-face control group, 10×5 m shuttle run test

In Fig.2, the 30-second trunk lift test shows a significant average increase, from 16.13 repetitions in the initial test to 19.00 repetitions in the final test, with a mean difference of 2.88 repetitions. The standard deviation increased from 2.75 to 7.07, and the coefficient of variation rose from 17.03% to 37.21%, indicating that although overall performance improved, progress was not uniform among students. The range of values shifted from 10–20 repetitions initially to 13–20 repetitions in the final test, highlighting that some students made greater gains than others.

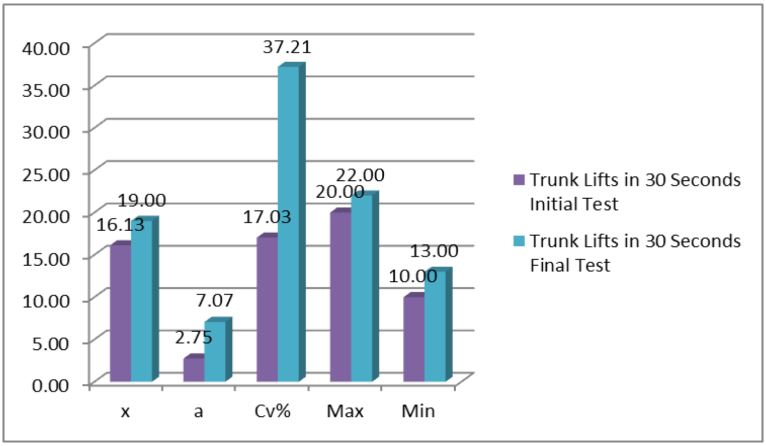

Fig. 2. Progress of students in the 30-second trunk lift test, face-to-face control group

In Fig. 3, the Static Balance Test shows a decrease in performance, with the mean time dropping from 7.13 seconds to 5.13 seconds, a difference of 2 seconds. The standard deviation increased from 1.50 to 3.86, and the coefficient of variation rose significantly from 21.01% to 75.30%, indicating extremely high variability among students. The maximum and minimum values were 9–5 seconds initially and 7–4 seconds in the final test, suggesting that the intervention's effect on balance was either negative or unevenly distributed.

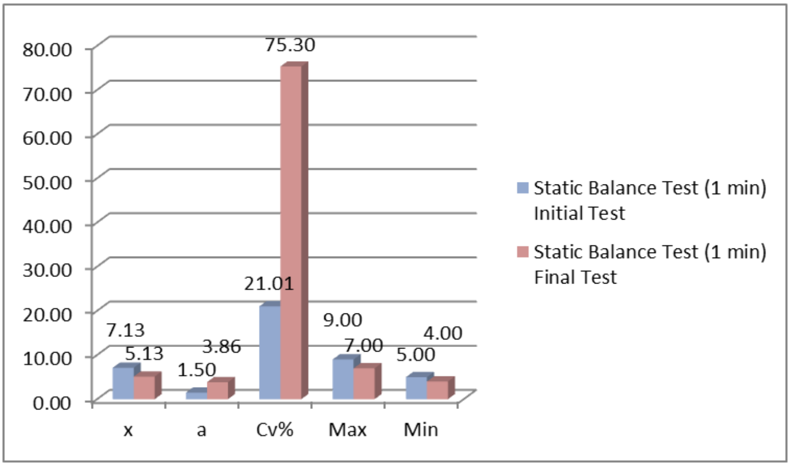

Fig. 3. Progress in the Static Balance Test – face-to-face control group

In Fig. 4, the Upper Limb Strength Test – push-ups shows an average improvement from 7.88 push-ups in the initial test to 10.31 push-ups in the final test, with a mean difference of 2.44 push-ups. The standard deviation was relatively high (5.50 initially, 5.72 finally), and the coefficient of variation was also high (69.88% initially, 55.46% finally), indicating that some students achieved significant gains while others showed smaller improvements. The range of values was 17–1 initially and 20–3 in the final test.

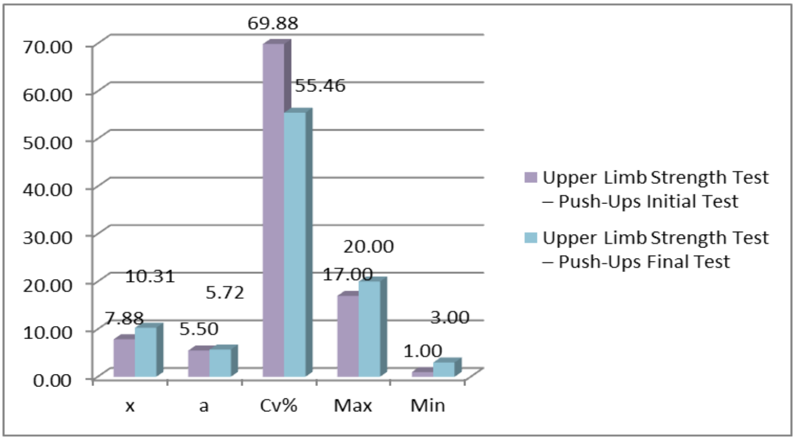

Fig. 4. Progress in the Upper Limb Strength Test – Push-ups – face-to-face control group

In Fig. 5, the Joint Mobility Test shows a decrease in the mean value from -7.88 to -10.31, a difference of -2.44, suggesting a reduction in mobility.

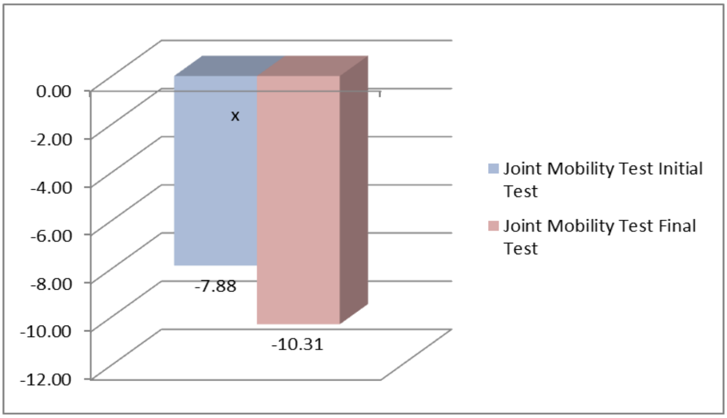

Fig. 5. Progress in Joint Mobility – face-to-face control group

In Fig. 6, the 10×5 m shuttle run test shows a slight improvement in speed. The initial mean time was 16.83 seconds, and the final mean time was 16.71 seconds, corresponding to a mean difference of 0.12 seconds. The standard deviation was 1.19 at the initial test and 1.10 at the final test, and the coefficient of variation was low, 7.04% at IT and 6.60% at FT, indicating relatively consistent performance among students. The maximum and minimum values were 18.82–13.67 seconds at IT and 18.39–13.65 seconds at FT. Therefore, it can be concluded that the intervention had a minor but positive effect on students' speed.

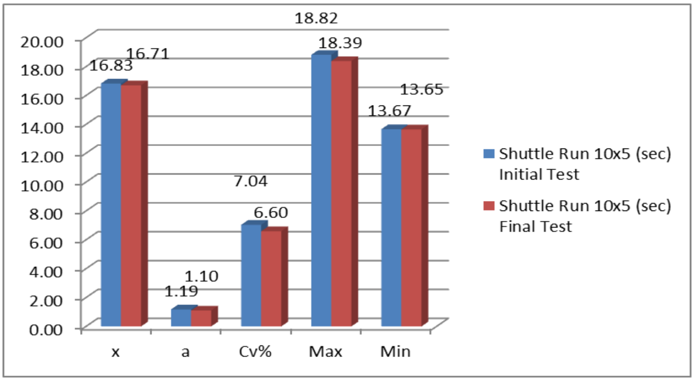

Fig. 6. Progress in the 10×5 m Shuttle Run Test – online experimental group

In Fig. 7, the 30-second trunk lift test shows a moderate increase, from an initial mean of 15.31 repetitions at IT to a final mean of 16.38 repetitions at FT, with a mean difference of 1.06 repetitions. The standard deviation was similar between the initial and final tests (1.89 vs. 1.86), and the coefficient of variation slightly decreased from 12.33% to 11.34%. The range of values was 18–11 repetitions at IT and 19–13 repetitions at FT, indicating that most students achieved consistent progress.

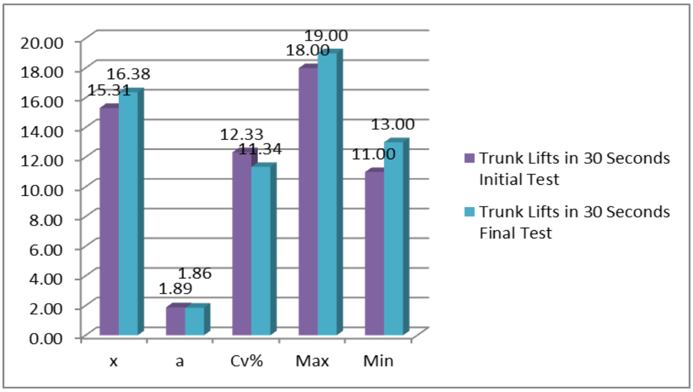

Fig. 7. Progress in the 30-Second Trunk Lift Test – online experimental group

In Fig. 8, the Static Balance Test shows a decrease in mean performance, from 7.50 seconds at IT to 6.94 seconds at FT, with a mean difference of 0.56 seconds. The standard deviation was 1.15 at IT and 1.29 at FT, and the coefficient of variation slightly increased from 15.40% to 18.59%, suggesting slightly greater variability among students after the test. The maximum values remained unchanged (9 seconds), while the minimum values decreased from 6 to 5 seconds. This indicates that, for some students, static balance was maintained, while others showed slight declines.

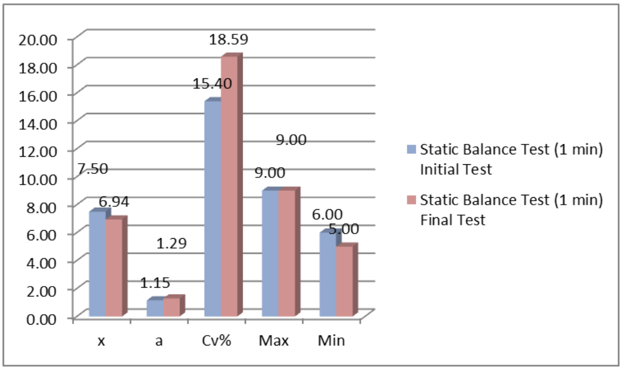

Fig. 8. Progress in the Static Balance Test – online experimental group

In Fig. 9, the Upper Limb Strength Test (push-ups) shows an average increase from 7.81 push-ups at IT to 8.69 push-ups at FT, with a mean difference of 0.88 push-ups. The standard deviation was similar between the initial and final tests (5.06 vs. 4.94), and the coefficient of variation was high but slightly lower after the physical education lessons (64.80% at IT and 56.82% at FT), indicating that progress was uneven among students, although a slight uniformity was observed. The maximum values increased from 17 to 18 push-ups, while the minimum values rose from 2 to 4 push-ups.

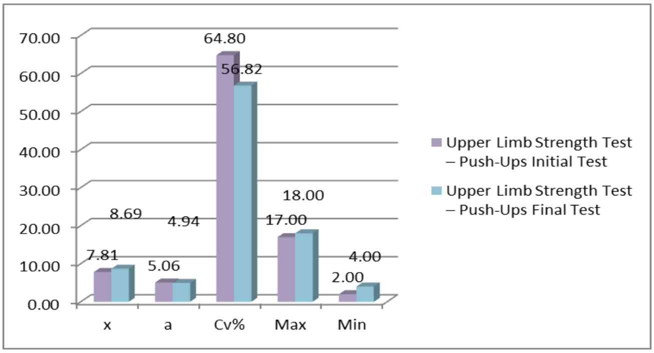

Fig. 9. Progress in the Upper Limb Strength Test (Push-ups) – online experimental group

In Fig. 10, the Joint Mobility Test shows a slight decrease in the mean value, from -7.81 at IT to -8.69 at FT, with a mean difference of -0.88. This suggests that joint mobility was not significantly stimulated by the intervention, and a slight reduction was even observed in some individuals.

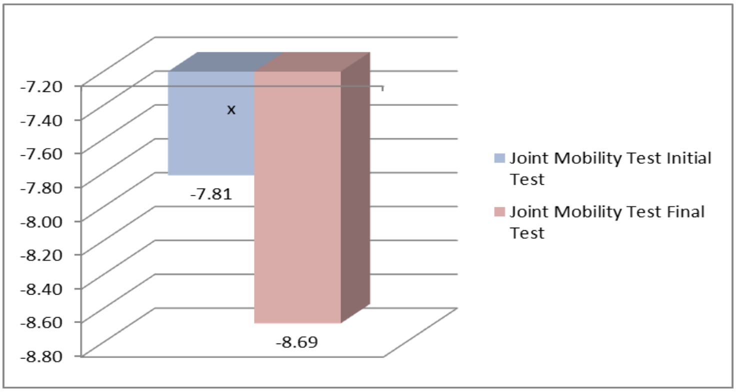

Fig. 10. Progress in Joint Mobility – online experimental group

In Fig. 11, the 10×5 m shuttle run test shows that the face-to-face control group recorded a mean time reduction from 16.66 seconds to 16.44 seconds, with a mean difference of 0.23 seconds. The online experimental group had a slight reduction from 16.83 seconds to 16.71 seconds, with a difference of 0.12 seconds. The difference between the two groups regarding improvement was 0.10 seconds, indicating a moderate effect of the intervention on speed.

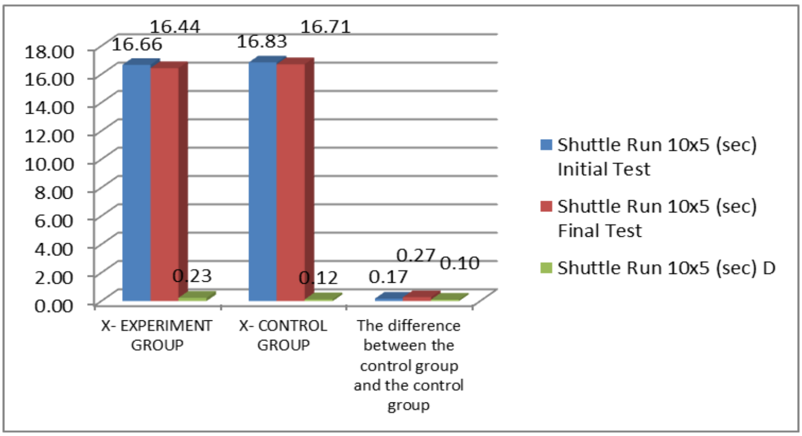

Fig. 11. Comparison of Speed Progress in the 10×5 m Shuttle Run Test between the Face-to-Face Control Group and the Online Experimental Group

In Fig.12, the 30-second trunk lift test shows that the control group progressed from 16.13 to 19.00 repetitions, with a mean difference of 2.88 repetitions. The online experimental group increased from 15.31 to 16.38 repetitions, with a mean difference of 1.06 repetitions. The difference between the two groups is 1.81 repetitions.

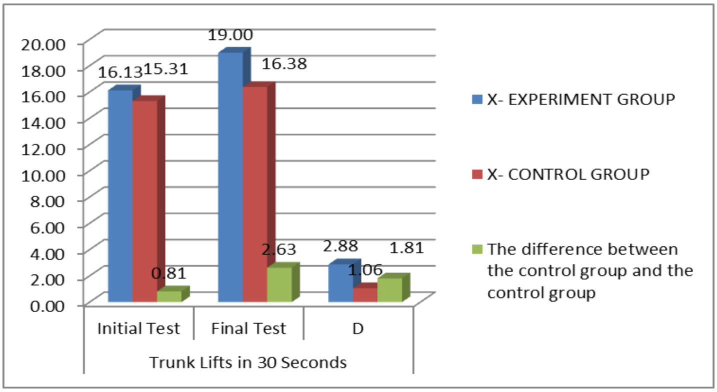

Fig. 12. Comparison of Progress in the 30-Second Trunk Lift Test between the Face-to-Face Control Group and the Online Experimental Group

In Fig. 13, the 1-minute Static Balance Test shows that the face-to-face control group recorded a decrease in mean time from 7.13 seconds to 5.13 seconds, a difference of 2 seconds. The online experimental group decreased from 7.50 seconds to 6.94 seconds, a difference of 0.56 seconds. The difference between the two groups is 1.44 seconds, indicating that the intervention did not have a positive effect on static balance, and performance declined more in the control group.

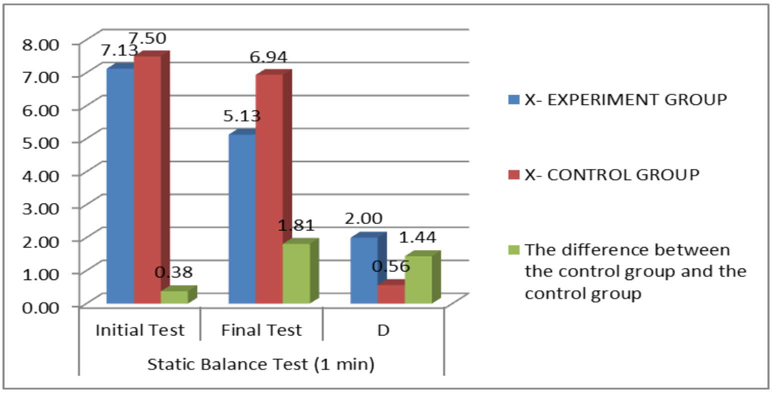

Fig. 13. Comparison of Progress in the 1-Minute Static Balance Test between the Face-to-Face Control Group and the Online Experimental Group

In Fig. 14, the Upper Limb Strength Test – push-ups shows that the control group increased from 7.88 to 10.31 push-ups, with a mean difference of 2.44 push-ups. The experimental group increased from 7.81 to 8.69 push-ups, with a mean difference of 0.88 push-ups. The difference between the two groups of 1.56 push-ups suggests a positive effect of the intervention on upper limb strength, greater than the spontaneous progress of the experimental group.

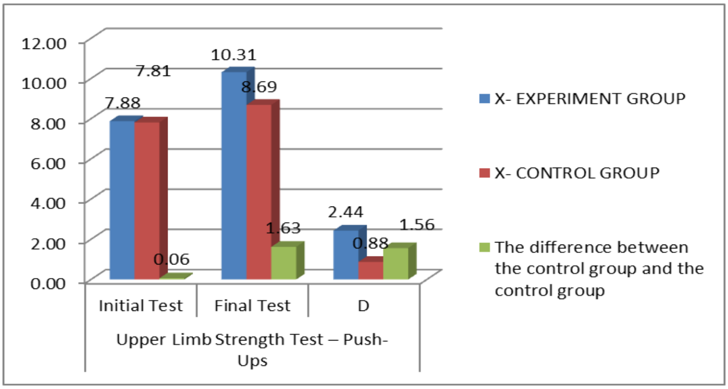

Fig. 14. Comparison of Progress in the Upper Limb Strength Test (Push-ups) between the Face-to-Face Control Group and the Online Experimental Group

In Fig. 15, the Joint Mobility Test shows that the control group decreased from -7.88 to -10.31, a difference of -2.44. The experimental group decreased from -7.81 to -8.69, a difference of -0.88. The difference between the two groups is -1.56, indicating that the applied program did not improve joint mobility and that the decrease was more pronounced in the control group.

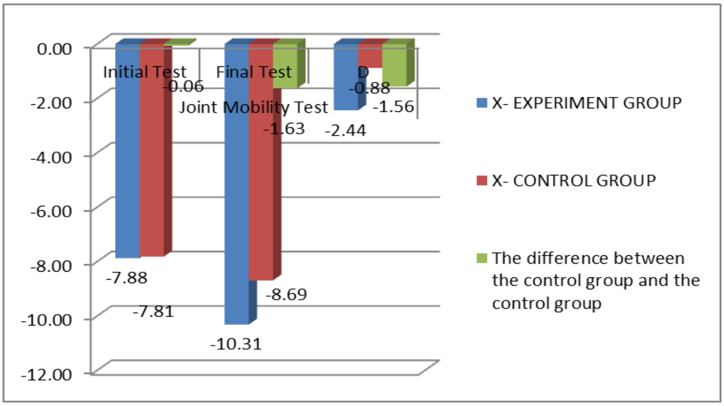

Fig. 15. Comparison of Joint Mobility Progress between the Face-to-Face Control Group and the Online Experimental Group

DISCUSSION

The results of the study conducted by (Bayburtlu et al., 2024) highlighted, through a quantitative pretest–posttest design with a single group of 34 primary school students, significant improvements in motor competence ($p<0.05$) following a hybrid physical activity program conducted over 8 weeks, both face-to-face and online via the Moodle platform. Similarly, the study by (Melero et al. 2021) demonstrated that a hybrid physical education program implemented over 9 months with 150 adolescents led to significant increases in physical fitness and physical activity levels, as well as a reduction in sedentary time ($p<0.05$), confirming the effectiveness of an approach based on personal responsibility and gamification.

CONCLUSIONS

In the control group, the implementation of the physical program for fourth-grade students led to significant increases in abdominal strength (trunk lifts) and upper limb strength (push-ups), as well as a slight improvement in speed (10×5 m shuttle run), confirming the effectiveness of exercises adapted to a hybrid context. The static balance and joint mobility tests showed stagnation or decline, indicating the need to include specific exercises for these components. High coefficients of variation highlight significant differences between students, emphasizing the importance of adapting exercises to each individual's level. The study confirms that varied and personalized methods allow the maintenance and development of basic motor skills even in hybrid learning conditions, recommending the inclusion of additional exercises for balance and mobility and tailoring physical tasks to each student's fitness level.

AUTHOR CONTRIBUTIONS

LUNGU Adrian Constantin and Vizitiu Lakhdari Elena contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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IMPACT OF PLYOMETRIC EXERCISE ON BALANCE REGULATION IN CHILDREN AND YOUTH WITH AUTISM SPECTRUM DISORDER

Dragoş Adrian MANIU[1], Emese Agnes MANIU[1*]

ABSTRACT. ***Background*:** Motor coordination difficulties and impaired postural stability are commonly observed in children and adolescents with Autism Spectrum Disorder (ASD), often limiting their ability to engage in everyday physical tasks and recreational activities. Although numerous strategies have been implemented to address these motor impairments, the specific impact of plyometric exercise on balance outcomes in this population has not been thoroughly examined. ***Objective****:* This research aimed to evaluate the influence of a systematically designed plyometrictraining program on balance control in school-aged individuals with ASD. ***Methods****:* Thirty participants (15 control group, 15 experimental group) between the ages of 10 and 15 years, all formally diagnosed with ASD, took part in a 12-week intervention. 15 children participated in plyometric exercise sessions; 15 children did not attend any form of exercise session during the 12 weeks. Pre- and post-training assessments were conducted using two standardized tools: the Mini Balance Evaluation Systems Test (Mini-BESTest) and the balance component of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2). ***Results****:* Statistical analysis demonstrated that the group undergoing plyometric training exhibited significant enhancements in both static and dynamic balance when compared to the control group, with results showing a p-value of less than 0.05. ***Conclusion****:* The findings suggest that plyometric training can serve as a beneficial and motivating approach to support balance development in children and adolescents on the autism spectrum.

Keywords: balance, autism spectrum disorder, visually impaired

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INTRODUCTION

Recent research suggests that Autism Spectrum Disorder (ASD) affects more than just communication, cognition, and emotional regulation—it also significantly impacts motor control (American Psychiatric Association, 2013). Although motor difficulties are not part of the core diagnostic criteria for ASD, they are frequently observed and often resemble those seen in developmental coordination disorder (DCD) (Sumner et al., 2016). Such motor challenges in early childhood can hinder participation in physical activities with peers, thereby reducing opportunities for social engagement and developmental progression.

From a cognitive science perspective, motor difficulties in ASD can be understood through disruptions in sensory processing, cognitive motor planning, and the timing and sequencing of muscle activation. Studies have indicated that individuals with ASD may experience impairments at each of these levels, which collectively contribute to challenges in motor coordination and execution (Stins & Emck, 2018).

Upright standing is a complex, highly regulated process that involves both open- and closed-loop control mechanisms (Collins & De Luca, 1993). While the body maintains near-equilibrium during quiet standing, it must constantly respond to internal and external disturbances through postural adjustments. These responses depend on the integration of multisensory input to determine body orientation, along with appropriate motor outputs to maintain or regain balance. Importantly, balance control is not solely governed by spinal reflexes—it also engages higher-order brain structures, including the motor cortex, cerebellum, basal ganglia, vestibular cortex, and brainstem. In individuals with ASD, multiple studies have shown that postural control is often impaired, and that these impairments can correlate with the severity of ASD symptoms (Stins & Emck, 2018).

Plyometric exercise, which involves rapid movements utilizing the muscle stretch-shortening cycle, has been shown to enhance both static and dynamic balance (Kons et al., 2023). Research indicates that plyometric training—whether horizontal or vertical—can significantly enhance stabilization in trained individuals, such as young athletes (Granacher and Behm, 2023), and improve their ability to respond effectively to perturbations (Moran et al., 2021)

The objective of the present study was to evaluate the effectiveness of a systematically structured plyometric training program in improving static and dynamic balance control in school-aged children with autism spectrum disorder (ASD).

MATERIAL AND METHODS

Participants

A total of 30 children with ASD (16 females and 14 males), aged between 10 and 15 years, were recruited from a local school. Eligibility criteria included no prior involvement in structured balance training and the capacity to respond to clear verbal commands. Written informed consent was obtained from the participants' legal guardians before study enrolment.

Procedure

The intervention consisted of a systematically designed plyometric training program implemented over a 12-week period, 2 sessions a week, 50 minutes per session. The program included age-appropriate plyometric exercises such as vertical and horizontal jumps, squat jumps, lateral jumps, hopping drills, and controlled landing tasks. These exercises were selected to stimulate the stretch–shortening cycle and improve neuromuscular performance.

The training protocol was specifically structured to target both static and dynamic balance. Static balance was addressed through exercises requiring postural stabilization following landing phases and controlled single-leg stance positions. Dynamic balance was developed through movement-based plyometric tasks involving directional changes, coordinated jumping sequences, and controlled body displacement.

Exercise intensity and complexity were progressively adjusted according to participants' capabilities to ensure safety and optimal adaptation. All sessions were conducted under professional supervision to ensure correct technique and minimize injury risk.

Static and dynamic balance were assessed before and after the intervention using standardized testing procedures.

Materials

The Mini Balance Evaluation Systems Test (Mini-BESTest) and the balance component of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) was used to assess balance (Baldwin, Kinsella, & Byrne, 2024).

Data analysis

Statistical analysis was performed using the MedCalc® Statistical Software version 23.3.7 (MedCalc Software Ltd, Ostend, Belgium; https://www.medcalc.org; 2025). Data were characterized by mean and standard deviation. Comparisons between measurements were performed using the two-way repeated measures ANOVA. The p value <0.05 was considered statistically significant.

RESULTS

The following section presents the quantitative outcomes of the 12-week plyometric training intervention on balance performance in school-aged children with ASD. Pre- and post-intervention measurements for static and dynamic balance were obtained using the Mini Balance Evaluation Systems Test (Mini-BESTest) and the balance subscale of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2). Descriptive statistics (means ± standard deviations) and inferential analyses, including paired and independent samples tests, were conducted to evaluate within-group and between-group differences. Statistical significance was set at $p < 0.05$. The results are reported to assess the efficacy of plyometric training in enhancing balance outcomes relative to a non-exercising control group.

Following the data analysis, no statistically significant change was observed in the control group (Table 1).

Table 1. The Balance Evaluation Systems Test (BESTest)for the control group

	Mean	St. deviation	N
INITIAL	16.00	1.690	15
FINAL	15.87	1.767	15

The experimental group showed statistically significant differences between the baseline and post-intervention assessments p≤0, 05 (Table 2).

Table 2. The Balance Evaluation Systems Test (BESTest)for the experimental group

	Mean	St. deviation	N
INITIAL	16.00	1.309	15
FINAL	21.20	1.971	15

When comparing the groups, no significant differences were observed at the initial assessment. However, at the final evaluation, following the 12-week intervention, a statistically significant difference was found between the control group and the experimental group p≤0, 05 (Table 3).

Table 3. The Balance Evaluation Systems Test (BESTest)

	Control group		Experimental group	
	Mean	**St.dev**	**Mean**	**St.dev**
INITIAL	16.00	1.690	16.00	1.309
FINAL	15,86	1.767	21.20	1.971

Note: p≤0, 05

Following the data analysis, no statistically significant change was observed in the control group (Table 4).

Table 4. The BOT-2 for the control groupl group

	Mean	St. deviation	N
INITIAL	22.80	3.278	15
FINAL	22.93	3.105	15

The experimental group showed statistically significant differences between the baseline and post-intervention assessments p≤0, 05 (Table 5).

Table 5. The BOT-2 for the experimental group

	Mean	St. deviation	N
INITIAL	22.93	3.011	15
FINAL	32.93	2.374	15

When comparing the groups, no significant differences were observed at the initial assessment. However, at the final evaluation, following the 12-week intervention, a statistically significant difference was found between the control group and the experimental group p≤0.05 (Table 6).

Table 6. The BOT-2. Comparation between the groups

	Control group		**Experimental group**	
	mean	St.dev	mean	St.dev
INITIAL	22,80	3.278	22,93	3.011
FINAL	22,93	3.105	32,93	2.374

Note: p≤0, 05

DISCUSSION

Children and adolescents with ASD often experience impairments in balance and motor control. Postural control difficulties are well-documented: poorer performance in static and dynamic balance tasks relative to neurotypical peers; more sway in center-of-pressure measures; and associations between severity of core autism features (e.g. repetitive behaviors) and poorer motor control (Favilene et al 2025).

Because balance is foundational to many motor skills and daily functioning (walking, coordination, fall prevention), interventions aimed at improving balance are considered important in ASD. Exercise-based interventions broadly have shown benefit. For example, a meta-analysis of 12 randomized control trial (children with ASD aged 3-18) found that exercise interventions significantly improved balance (standardized mean difference ~ 0.86, $p < 0.05$). Importantly, interventions longer than eight weeks had stronger effects (Li, H., & Zhang, R. 2025). Another meta-analysis of 15 studies (195 participants) found large positive effects for balance interventions in ASD (Djordjević et.al.2022).

Plyometric training (jumping, bounding, rapid stretch-shortening of muscles) is well-known in sports and rehabilitation settings for improving power, agility, and sometimes balance or stability. In populations with motor impairments (e.g., cerebral palsy), plyometric jump or combined plyometric-jump training has been found to significantly improve both static and dynamic balance. For example, a recent meta-analysis in youth with cerebral palsy (ages 9-15) found that plyometric jump training over 8-12 weeks (2-4 sessions per week) resulted in moderate effect size improvements in static and dynamic balance compared to controls (Garcia-Carrillo et al 2024).

In non-clinical populations, combining plyometric with balance training tends to yield larger improvements in dynamic balance and related motor performance compared to plyometric alone or standard practice. For instance, in adolescent Taekwondo athletes, a combined balance + plyometric (PT) intervention produced superior gains in dynamic balance (as measured by stability indices) compared to PT alone (Shen X. 2024). Also, in children, combining plyometrics + balance yielded better outcomes for static & dynamic balance, agility, etc., than plyometric only (Chaouachi et al 2014).

While the general exercise-balance literature for ASD is fairly robust, there appears to be little or no published research specifically applying plyometric training protocols to ASD populations (at least none identified in recent meta-analyses or trials I located). Most ASD studies focus on more traditional balance training (biofeedback, virtual reality, physical education programs, or general motor skills), not explosive or high-velocity stretch-shortening movements like plyometrics. For example:

- Biofeedback-based videogame or VR-based balance training has shown improvements in balance measures, postural sway, and even some reductions in autism symptom severity (Travers et al 2018).
- A six-month extracurricular physical education program improved dynamic balance in ASD children (Salvador-Garcia et al 2023).
- Pilates-style movement intervention showed benefit for flexibility and balance in ASD (Saraçoğlu & Şirinkan 2016).

Thus, there is a gap in exploring plyometric training in ASD: its safety, efficacy, and how its intensity or volume needs to be adapted.

In the present study, the experimental group demonstrated significant improvements in dynamic balance following a structured 12-week plyometric training program. The program was designed to progressively challenge lower limb strength, coordination, and neuromuscular control through a variety of bodyweight plyometric exercises. These included jumping in place, jumping up onto a bench, jumping down from a bench, jumping on one leg in place, as well as single-leg jumps onto and off a bench.

This combination of bilateral and unilateral plyometric tasks provided graded exposure to the stretch-shortening cycle, requiring participants to develop both explosive power and postural stability. Importantly, exercises such as jumping down and up from a bench demanded eccentric control and reactive balance during landing and takeoff, likely contributing to the observed improvements in dynamic postural control.

Post-intervention assessments revealed that the experimental group had enhanced performance in balance tasks—particularly those requiring dynamic weight shifts and single-leg stability—relative to their pre-test baseline and the control group. These findings align with previous studies showing that plyometric training improves dynamic balance in typically developing children and athletes (Hammami et al., 2016; Chimera et al., 2044), although the present study is, to our knowledge, among the first to apply such a program in children with Autism Spectrum Disorder (ASD).

Given that individuals with ASD often exhibit impaired balance and sensorimotor integration (Fournier et al., 2010; Li et al et al., 2023), these results suggest that appropriately tailored plyometric training may serve as a viable and effective intervention to target these deficits.

The improvements observed after 12 weeks are also consistent with meta-analytic findings indicating that intervention duration greater than 8 weeks is typically required to produce measurable gains in balance among children with ASD (Wang et al., 2024).

CONCLUSIONS

The findings of this study demonstrate that a 12-week plyometric training program led to significant improvements in balance performance as measured by the Mini-BESTest and BOT assessments in the experimental group. In contrast, the control group showed no significant changes over the same period. These results suggest that plyometric training is an effective intervention for enhancing balance, coordination, and overall motor performance in the studied population. The lack of progress in the control group further emphasizes the impact of targeted physical training in achieving functional gains. Future studies should explore the long-term effects and optimal parameters of plyometric programs across different age groups and functional levels for children with ASD.

AUTHOR CONTRIBUTIONS

Author 1and 2 contributed to the design and implementation of the research, author 1 and 2 contributed to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this study.

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STAKEHOLDERS AND SUSTAINABLE VALUE CREATION IN FOOTBALL CLUBS: A COMPARATIVE ANALYSIS BETWEEN THE BRITISH MODEL AND ROMANIAN REALITIES

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ABSTRACT. ***Introduction***: Professional football has evolved far beyond the boundaries of sport, becoming a global industry with major economic, social, and cultural impact. In this context, the way clubs are governed and how they manage their stakeholders are crucial factors for both performance and sustainability. ***Aim***: The aim of this research is to identify the dominant governance patterns in English Football and compare them with the realities of Romania's Liga 1. ***Methods***: This study analyzed academic articles published between 2010 and 2025, focusing on stakeholder theory, shared value, sustainable entrepreneurship in football, and football clubs' social responsibility. For the applied section, seven Romanian Liga 1 clubs were investigated. ***Results***: The analysis revealed that Romanian clubs oriented towards social and cultural capital maintain stable relationships with stakeholders, achieving a positive equilibrium score. Clubs focused almost exclusively on economic capital face major disequilibria, manifested through fan protests and reputational crises. ***Conclusions***: The study confirms that stakeholder integration in club governance is a fundamental condition for sustainability.

Keywords: professional football, sustainable value, Romanian Ligue 1, Premier League

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INTRODUCTION

Professional football has long surpassed its status as a mere sport, becoming a global industry with a significant impact on the economy, culture, and society. With an estimated European market value exceeding €30 billion, football clubs now operate as complex organizations that manage diverse stakeholders and multiple forms of capital — economic, social, cultural, and symbolic. Understanding how these clubs create value for their stakeholders is essential to assessing their sustainability and organizational performance.

This paper examines governance models and entrepreneurial orientations in professional football, drawing on stakeholder theory (Freeman, 2010), shared value (Porter & Kramer, 2011), and sustainable entrepreneurship (Bull & Whittam, 2021). It compares the British model — characterized by profit-oriented global investors — with the Romanian context, where financial pressures, political influences, and community attachment shape stakeholder relationships differently. The analysis highlights a growing legitimacy crisis within professional football, rooted in the tension between the “legal ownership” of investors and the “moral ownership” claimed by fans and local communities.

The theoretical framework employs the stakeholder salience model (Mitchell et al., 1997), which helps identify dominant and discretionary actors, emphasizing the need for participatory governance. In football, value creation extends beyond sporting results or financial profit, emerging from a relational ecosystem built on legitimacy, fairness, and social responsibility. The shared value model provides a useful lens to analyze clubs that align economic goals with social impact through initiatives in education, inclusion, and health promotion.

However, in many European contexts — particularly in Romania — corporate social responsibility remains largely superficial, and entrepreneurial orientation is often skewed toward economic capital. Achieving long-term sustainability requires a strategic vision that balances economic, cultural, social, and symbolic capital, redefining value not merely as profit but as a durable relationship between clubs, stakeholders, and their communities.

PURPOSE OF THE STUDY

The main objective of this paper is to analyze how professional football clubs create value in relation to their stakeholders and to identify governance models that can support the long-term sustainable development of a club. The study specifically aims to highlight the differences and similarities between the British model — highly commercialized and oriented toward multiple forms of capital (economic, social, cultural, and strategic) — and the realities of Romanian clubs, where dynamics are often shaped by political influences, economic instability, and transitional management practices.

Through this research, we seek to formulate practical recommendations for Romanian clubs, enabling them to build coherent development strategies grounded in stakeholder relationships and the concept of sustainable value creation.

MATERIAL AND METHODS

This study employed a qualitative, comparative research design focused on stakeholder analysis and value creation models within professional football clubs. The research examined two main samples:

• British clubs — specifically the 44 teams from the Premier League and English Football League Championship — analyzed through secondary sources following the framework proposed by Bull & Whittam (2021);

• Romanian top-division clubs selected for their economic, social, and sporting relevance: CS Universitatea Craiova, CFR Cluj, Universitatea Cluj, FCSB, Dinamo București, Rapid București, and Farul Constanța.

These clubs were chosen because they represent diverse organizational structures, stakeholder relationships, and historical, social, and economic contexts — ranging from privately funded to publicly supported or hybrid models. Data were collected from publicly available sources, including official club websites, press releases, media reports, fan forums, academic studies, and, where accessible, official financial documents.

I used a qualitative, comparative case study methodology, applied to:

• British clubs – by interpreting secondary data from the literature (Bull & Whittam, 2021).

• Romanian clubs – through document analysis and stakeholder relationship evaluation, based on stakeholder theory (Freeman, 2010; Mitchell et al., 1997) and the four-capital model (Groen et al., 2008).

Analysis steps:

- Identification of main and secondary stakeholders (fans, investors, authorities, sponsors, media, youth academies, etc.).
- Application of the four-capital grid (economic, social, cultural, strategic) to assess each club's orientation.
- Evaluation of balance or imbalance in club–stakeholder relations (protests, image crises, fan disengagement, conflicts).

- Triangulation of data from official statements, media reports, and fan reactions.
- Synthesis table comparing seven Romanian clubs by orientation and stakeholder relationship status.

This approach allowed direct comparison between Romanian and British football governance models, using Bull & Whittam's (2021) framework and an adapted balance score for stakeholder relations.

RESULTS

The analysis of the seven Liga 1 football clubs examined how they relate to their stakeholders (fans, local authorities, investors, sponsors, etc.) and which types of capital — economic, social, cultural, and strategic — dominate their organizational strategies.

Using the interpretive framework inspired by Bull & Whittam (2021), significant differences were observed between clubs in terms of the balance of the club–stakeholder relationship, depending on how these forms of capital are managed.

Table 1. Evaluation of capital orientation and club–stakeholder relationship

Club	Economic	Social	Cultural	Strategic	Relation with stakeholders	Equilibrium (E)
CS Universitatea Craiova		✓	✓		Active community involvement	+1
CFR Cluj	✓			✓	Centralization, fan spacing	0
Universitatea Cluj		✓	✓		open communication, transparency	+1
FCSB	✓				Tense relationship, protests	–1
Dinamo București	✓		✓		Repeated crises, disengaged fans	–1
Rapid București			✓	✓	Ambivalent relationship, mixed feedback	0
Farul Constanța		✓		✓	Local support, social projects	+1

Based on the collected data, the main findings are:

1. Clubs with a social–cultural orientation (Universitatea Cluj, Farul, CS U Craiova) maintain stable and harmonious relationships with stakeholders, scoring +1 on relational balance.
2. Clubs focused mainly on economic capital (FCSB, Dinamo) show the highest tensions, marked by protests, fan disengagement, and lack of transparency, scoring –1.
3. Mixed-orientation clubs (economic–strategic or cultural–strategic), such as CFR Cluj and Rapid, display ambivalent situations, alternating cooperation and conflict, with a neutral score (0).
4. Social capital correlates positively with fan loyalty, community engagement, and public image, while its absence increases vulnerability to relational crises.
5. Clubs with strategic capital (e.g., Farul, Rapid) use long-term partnerships, but their impact depends on integration with other forms of capital.

DISCUSSIONS

The comparative analysis of governance and stakeholder management models between British football (Premier League/EFL) and Romanian football (Liga I) revealed significant discrepancies, confirming the central hypotheses of the study. The British model is distinguished by a corporate, transparent, and highly regulated structure, geared towards long-term sustainability. Financial regulations, such as the "Profitability & Sustainability" (P&S) rules, and legislative proposals for an independent regulator, underscore a formal commitment to financial discipline and stakeholder protection. In contrast, the Romanian model is marked by unstable, fragmented governance, dominated by private interests, often lacking coherent regulations and uniform enforcement of sanctions for economic imbalances.

The results align with literature correlating the dominant type of capital with the state of the club–stakeholder relationship. A pronounced relational imbalance was identified in Romanian clubs focused exclusively on economic or strategic capital, neglecting the social and cultural dimensions. Clubs like FCSB or Dinamo exhibit visible signs of stakeholder alienation, a situation that, according to research, affects long-term operational stability, not just reputation. This observation validates the four capitals model (Groen et al., 2008), demonstrating the utility of a multidimensional approach to organizational value, beyond the economic criterion.

A key finding is that clubs in Romania that have adopted a more stakeholder-oriented strategy (e.g., Universitatea Cluj, Farul Constanța) benefit from an increased level of balance and community support. This suggests that investments in social and cultural capital are not mere philanthropic actions, but fundamental strategies for loyalty, resilience, and stability. The British model offers a clear lesson in this regard: a transparent governance framework, shared responsibilities, and clear financial regulations are essential. The lack of a similar framework in Romania undermines club credibility and stability, confirming Baumol's (1996) observations on the existence of unproductive entrepreneurship when strategic and economic orientation is disconnected from local stakeholder interests.

From a theoretical perspective, the study extends the applicability of stakeholder theory (Freeman, 2010) in the context of Romanian football, demonstrating that even in systems marked by instability, a rigorous stakeholder analysis provides a solid framework for interpreting organizational performance. The imbalance between economic and social capital, identified in the case of Romanian clubs, resonates with symptoms of "detachment, disenchantment and protest" described by Bull & Whittam (2021) in British football. Therefore, the present research confirms relevant international trends, emphasizing the importance of a systemic, value-based approach in stakeholder evaluation and integration, similar to the conclusions of Yiapanas et al. (2019).

CONCLUSIONS

The comparative analysis of governance and stakeholder management models in British and Romanian football revealed significant differences with direct implications for club performance and sustainability. Stakeholder integration emerged as a key factor of stability and resilience. In British football, this process is formalized and regulated, whereas in Romania it remains limited, informal, and often reactive.

A balanced interaction between economic, social, cultural, and strategic capital is essential for sustainable growth. Romanian clubs that invest in social and cultural dimensions (such as Universitatea Cluj, Farul, and CS U Craiova) maintain stronger ties with their communities, while those focused mainly on economic capital (FCSB, Dinamo) face recurring tensions and instability.

Financial transparency and strict regulations are defining elements of the British model, ensuring accountability and preventing managerial excesses. The absence of similar mechanisms in Romania explains the recurrent financial crises and insolvency cases affecting many clubs.

Finally, shared value and social responsibility (CSR) are no longer optional but strategic imperatives. Clubs that implement educational and community programs strengthen both reputation and fan loyalty, aligning with global trends linking sport and social impact. The British model offers valuable lessons, but its adaptation in Romania requires professionalized management and a coherent regulatory framework. Sustainable development in Romanian football thus depends on shifting governance from a profit-centered logic to one based on stakeholder value and collaboration.

LIMITATIONS

The analysis relied exclusively on secondary sources and publicly available data, which limits access to the internal perspectives of clubs, such as managerial policies or behind-the-scenes strategic decisions. Moreover, the relatively small number of clubs examined (n=7) reduces the generalizability of the findings. Additionally, the absence of direct inquiry — such as interviews with supporters, managers, or other stakeholders — restricts the depth of interpretation and prevents a more nuanced understanding of stakeholder perceptions.

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THE INTERACTION BETWEEN STATIC AND DYNAMIC BALANCE PARAMETERS AND GENERAL AND SPECIFIC COGNITIVE SKILLS IN MOTOR ACTIVITIES IN PREADOLESCENTS

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ABSTRACT. ***Introduction***: Balance and cognitive abilities share common neural structures and processing areas, especially within the cerebellum and prefrontal cortex. ***Objective****:* The objective was to analyze the relationship between general and specific cognitive skills related to motor activities and balance in preadolescents. ***Material and Methods***: This research included children aged 10-13 years (N=116) from a middle school in Iași, Romania**.** The subjects performed static balance tests on a force plate and a dynamic balance test. The cognitive skills specific to motor activities were evaluated using the Witty Sem device, while general cognitive skills were assessed using the Raven Progressive Matrices. ***Results***: A series of good correlations were observed between the parameters of static balance and the results of attention, working memory, visual memory, and IQ tests. After linear regression, some static balance parameters and the force applied on the support leg explained over 30% of the variance in cognitive abilities. ***Discussion****:* The findings of this research are consistent with previous studies highlighting the interdependence between balance control and cognitive functions, particularly in relation to executive abilities and processing speed. ***Conclusions****:* The correlations obtained support the hypothesis that both balance and cognition rely on shared neural mechanisms located in the cerebellum and prefrontal cortex. Also, the identified associations between applied force and IQ could represent an additional research topic, as we have not found studies in the specialized literature that investigate this link.

Keywords: Static balance; IQ; attention; visual memory; working memory**.**

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INTRODUCTION

Physical and sports activities manage to improve certain cognitive abilities such as working memory (Biino, et al., 2021), attention, memory (Sumińska, 2021), academic performance (Lambert, Ford, & Jeanes, 2022), and can also enhance processing speed after engaging in a moderate to high-intensity activity before taking a cognitive test (Kekäläinen, et al., 2023).

Certain authors (Divandari et al., 2023; Meunier, et al., 2021; Yan, et al., 2022) report that both static and dynamic balance can require different cognitive processes, such as executive functions, episodic memory, processing speed, and cognitive decline, these results being obtained on elderly subjects.

Yan et al. (2022), following the results of a study conducted on 8,499 adults over the age of 45, concluded that good static balance was significantly associated with higher cognitive function (episodic memory, mental state, and global cognition) and lower cognitive decline. Meunier and his collaborators (2021) also found an association between low balance ability and poorer cognition in a cross-sectional analysis of 4,811 adults aged over 76.

The cerebellum, an area of the brain heavily involved in both balance and cognitive abilities such as visual-spatial attention, working memory, and language (Zhang et al., 2023), undergoes substantial development in early life and continues to mature until approximately 15 years of age (Tiemeier et al., 2010).

Additionally, the prefrontal cortex is involved in attention, motor planning, and executive functions (Sugihara et al., 2021), and at the same time, certain studies demonstrate activation of the prefrontal cortex during the performance of a static and dynamic balance task (Wittenberg et al., 2017). Moreover, it is known that postural control and cognitive performance are affected during dual-task paradigms, suggesting that they use common areas of the brain.

Therefore, childhood can represent a sensitive period necessary for the development of important synapses and neuronal connectivity involved in the systems on which the optimal achievement of balance depends, and the evolution of cognitive capacity in childhood represents the beginning of a lifelong cognitive path (Hurst et al., 2013).

In children, positive correlations were found between static balance and attention at the age of 4-5 years (Abuin-Porras et al., 2018), with academic performance at the age of 5-6 years (de Waal, 2019), and additionally links were observed between dynamic balance, concentration ability, and academic performance in mathematics in 12-year-old children (Bataineh et al., 2017). At the same time, during adolescence (15 years old), higher cognition was associated with better midlife balance performance, with associations decreasing with age (Blodgett et al., 2018).

Additionally, performance IQ and visual-motor IQ had a strong association with static balance for the ages 7-13 years and 11-18 years. The weakest (insignificant) association of static balance was with verbal IQ. Moreover, a very strong association was found between the ability to maintain static balance at 7 years old and performance IQ at 16 years old (Jenni et al., 2013).

A similar result in the study conducted by Rigoli and colleagues (2012) was the specific link found between balance ability and total errors in the inhibition test in subjects aged 12-16 years. This link supports the accumulation of evidence for the attentional demands of children during postural tasks. The same result was observed in children aged 5-7, finding a link between static balance and the ability to switch attention, inhibition, and the capacity to update within working memory (Oberer et al., 2017).

Certain studies have not obtained results that demonstrate a correlation between balance and certain cognitive aspects, such as working memory, academic performance, and executive functions at the age of 12-16 years (Rigoli et al., 2012), cognitive development in children aged 1 year and 6 months (Veldman et al., 2019), and with the results on the Raven's Progressive Matrices test in children with an average age of 6 years and 4 months (Sadri et al., 2021).

Research interested in the correlation between static balance, dynamic balance, and cognitive abilities is numerous for elderly subjects. In contrast, studies conducted on subjects in childhood, preadolescence, and adolescence are found in a smaller number.

The purpose of this research was to verify whether certain balance variables correlate with general cognitive abilities and specific motor activity skills in preadolescents based on age and gender. We hypothesized that there would be certain correlations between the variables of static and dynamic balance and IQ, attention, visual memory and working memory in children aged 10–13 years.

MATERIAL AND METHODS

Participants

In this study, 116 subjects participated, students of the "George Călinescu" Middle School in Iași County, Romania, school for which we received the approval of the school management to conduct the tests. Inclusion criteria for subjects: to be aged between 10 years and 13 years and 11 months, to be clinically healthy, not to have a certificate of students with special educational needs, and to have parental consent. Exclusion criteria: to have physical or mental medical issues that may disrupt balance or cognitive abilities and to not complete all administered tests.

The subjects were divided into two groups, 10-11 years old (30 girls/30 boys) and a group of 12-13 years old (27 girls/29 boys), and within each group, a separate statistical analysis was conducted on female and male subjects.

We chose this age group for subjects because the cerebellum and prefrontal cortex (areas of the brain involved in both balance and cognitive skills) continue to mature during this period. Regarding cognitive skills specific to motor activities, attention matures around the age of 12, while memory and working memory mature around the age of 14.

Thus, considering that the psychomotor component, balance, is at the end of the developmental period, we divided the subjects into 2 groups because we wanted to observe at which age group (10-11 years or 12-13 years) we would identify the most significant correlations between balance components and cognitive abilities.

The study was approved by the Ethics Committee of Scientific Research of the Faculty of Physical Education and Sport at "Alexandru Ioan Cuza" University of Iași.

Procedure

The research was conducted in November 2023 at the "George Călinescu" Middle School in Iași, Romania. Participants were divided into two age groups (10–11 years and 12–13 years) and were tested while well rested, in the school's sports hall. The testing sessions were performed during the morning hours, in small groups, under the supervision of the research team.

Before testing, participants and their parents were informed about the purpose and objectives of the study and were assured of the confidentiality of their data and the right to withdraw at any time.

Materials

The evaluation of static balance was carried out using the Desmotec E-Board force plate. The balance maintenance task was performed on one leg (right and left) both with eyes open and closed, while the subject kept their hands on their hips. Desmotec E-Board measures the area encompassed within an ellipse of pressure points on each foot, the maximum and average force applied on the right/left side of the foot, and the percentage of unbalance.

To evaluate dynamic balance, we used the Bass test (Johnson & Leach, 1986; Rami, 2019). In the context of this test the subject has 10 squares (2.5 cm^2) stuck to the ground in front of it. The subject is on the starting line with the right foot. At the evaluator's signal, the subject jumps on the square number 1 with the left foot and maintains balance for 5 seconds while looking forward. After 5 seconds, the subject jumps with the right foot onto square number 2, maintaining their balance for the same number of seconds. The same thing is done on each square, jumping from one foot to the other. The evaluator will count the seconds on the stopwatch aloud to help the subject orient themselves temporally. If the subject puts their heel down or any other part of their body (foot, hand), the counting stops and the seconds maintained correctly by the subject are recorded. He receives 5 points if he covered the entire square with the ping pong ball, 3 points if he covered half of the square, 0 points if he didn't cover the square at all, and 1 point for each second the ping pong ball is held.

Specific cognitive abilities were evaluated using the Witty·SEM device: 2.1.11. We used the Divided Attention test to evaluate attention as well as response time. The subject has 4 traffic lights arranged in a line on a frame with distance between them in front of him. Two geometric shapes of different colors will be displayed on the two middle traffic lights. The traffic light on the left side has a "Y" on it, representing the answer "Yes," and the one on the right side has an "N," representing the answer "No." The subject stands in front of the frame where the traffic lights are located and must press "Y" if the two geometric shapes have the same color and "N" if the geometric shapes have different colors.

For visual memory, we used the Eye for Detail test. The subject is 2 meters away from the device and has 8 traffic lights arranged in an oval shape in front of them on the frame. On 3 of the traffic lights, 3 butterflies will appear in random order, 2 of which are identical, and one is different. After all 3 butterflies have appeared, a green dot will light up on the traffic lights where these shapes have appeared. The subject must move as quickly as possible and touch the green point on the traffic lights that showed the two identical butterflies, and then move back to the starting point.

For working memory, we used the Juggle test. The subject is 2 meters away from the device and has 8 traffic lights arranged in an oval shape in front of them on the frame. Numbers from 1 to 3 will appear on the traffic lights in ascending order and arranged randomly. After this, a green dot will appear on all the traffic lights, and the subject must press the corresponding traffic lights in the order the numbers appear (1, 2, 3...). After the first 3 repetitions, if the subject answers correctly, 4 numbers will appear, with the maximum number of numbers that can appear on the traffic lights being 6, but it depends on the correctness of the answers. In case the subject answers incorrectly repeatedly, the number of digits displayed will decrease to 2.

The Raven Progressive Matrices test was used to assess the intelligence quotient. The test includes 60 items, which the subjects received individually on sheets. Each item consists of an abstract drawing, often from a grouping of figures ("matrix"), from which a part is missing un element. The subject must decide, after examining the matrix, which is the unique figure (from the 6 or 8 offered on the same board under the matrix) suitable for the correct "completion" of the matrix. Simple trials are grouped into series of 12 matrices each, with the series being labeled from "A" to "E."

Data analysis

Within the statistical-mathematical method, we used the following: Mahalanobis distance - to identify data that exhibit an aberrant distance from the mean of the evaluated parameters; Shapiro-Wilk - analysis of the normality of data distribution in groups with fewer than 50 subjects; Pearson correlation - to establish the correlations between the mentioned parameters and cognitive abilities that exhibited a normal distribution of results; Spearman correlation - to establish the correlations between the mentioned parameters and cognitive abilities that do not have a normal distribution of results; Linear regression - to identify the degree of influence that balance parameters can have on general and specific cognitive abilities. Statistical significance was set at $p < 0.05$.

RESULTS

Correlations performed in the 10-11 year age group

In the group of 10-11-year-old boys, a good association was observed between a greater static imbalance on the left foot with eyes open and a smaller number of correct responses on the attention test (r=-0.576), and between a larger integrated surface of pressure points on the left foot with eyes closed and a better response time on the working memory test (r=-0.573).

A good correlation was also observed between a greater maximal force applied to the left side of the right leg with eyes closed and a slower response time on the working memory test (r=0.530) (Table 1).

In the group of 10-11 year old girls, a good association was observed between a low IQ and a larger integrated area of pressure points on the right foot with eyes closed (r=0.538) and between a greater maximum force applied to the right side of the left foot with eyes closed and a higher IQ score (r=0.566).

In contrast, the other parameters of static and dynamic balance showed a weak correlation with general cognitive abilities and those specific to motor activities (Table 2).

Following the use of linear regression, we were able to observe how much cognitive abilities are influenced by balance parameters. It was found that in the case of 10-11-year-old boys, static balance on the left foot with eyes open influenced the correct response results in the attention test by 33%, while the response time in the working memory test was influenced by 34% by the integrated surface of pressure points on the left foot with eyes closed and by 30% by the maximum force applied on the left side of the right foot with eyes closed (Table 1).

Table 1. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of boys aged 10-11 years

Variable	Correlation Parameter	R/p	R squared
UN_Lfoe (%)	CA_A (score)	-.576/.006	.330
A_Lfce (cm^2)	RT_WM (score)	-.573/.032	.346
MForce_LSide_RFce (Kg)	RT_WM (score)	.530/.011	.307

Legend: R - correlation coefficient; p - threshold of significance; UN – unbalance; Lfoe – left foot open eyes; A - area encompassed within an ellipse of pressure points; LFce – left foot closed eyes; MForce – maximum force applied; LSide – left side; RFce – right foot closed eyes; RA – correct answers; A – attention test; RT – response time; WM – working memory test.

In the case of the group of girls aged 10-11, the IQ results were influenced by 28% by the integrated area of pressure points on the right foot with eyes closed and by 32% by the maximum force applied on the right side of the left foot with eyes closed. Thus, the R-squared values indicate a fairly good influence in the case of boys to predict that these balance parameters have influenced the results of cognitive abilities, but also in the case of girls regarding the maximum force applied on the right side on the left foot with eyes closed (Table 2).

Table 2. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of girls aged 10-11 years

Variable	Correlation Parameter	R/p	R squared
A_RFce (cm^2)	IQ (score)	.538/.021	.289
MForce_RSide_LFce (Kg)	IQ (score)	.566/.006	.307

Legend: R - correlation coefficient; p - threshold of significance; A - area encompassed within an ellipse of pressure points; RFce – right foot closed eyes; MForce – maximum force applied; RSide – right side; LFce – left foot closed eyes; IQ – intelligence quotient.

Correlations performed in the 12-13 age group

In 12-13-year-old boys, a good association was observed between a higher integrated surface area of pressure points on the right foot with eyes open and a lower number of correct responses on the working memory test (r=-0.578).

Regarding the maximum and average force applied to each side of the leg in 12-13-year-old boys, good correlations were observed between a higher IQ and greater force applied to certain strength parameters with r values between 0.519 and 0.697 (Table 3).

In 12-13-year-old girls, it was observed that there is a good correlation between higher static balance on the left leg with eyes open and a lower number of correct responses on the visual memory test (r=-0.511), and between higher static balance on the right and left legs with eyes closed and better response speed (r=-0.551) and a decrease in correct responses on the attention test (r=-0.500), as well as a slower response time on the visual memory test (r=0.505).

Regarding the maximum and average force applied on each side of the leg, a good association is observed between a high IQ and a lower average force applied on the left side of the right leg with eyes closed (r=-0.687) and the average force applied on the right side of the left leg with eyes closed (r=-0.616). Good correlations were also observed between a slower response time on the visual memory test and greater force applied to certain strength parameters, with an r value between 0.507 and 0.581.

Good associations were also observed between the increase in correct responses on the visual memory test and the lower force applied on certain strength indices with an r value between -0.510 and -0.604, while a slower response time on the working memory test showed a good association with higher maximal force applied on the right side of the right leg with eyes closed (r=0.504) (Table 4).

In contrast, the scores on the dynamic balance test showed no correlation with general cognitive abilities or specific motor activity skills in either 12-13-year-old girls or boys.

Following the use of linear regression, the highest values of r-squared were observed in the case of 12-13-year-old boys, where IQ results were influenced by 46% by the average force applied to the right side of the left foot with eyes closed and by 48% by the maximum force applied to the left side of the right foot with eyes closed. In the case of 12-13-year-old girls, IQ scores were influenced by 47% by the average force applied to the left side of the right foot with eyes closed (Table 3).

However, more significant and numerous influences of balance parameters on cognitive abilities were observed in the group of boys aged 12-13 than in girls, where in many associations the R-squared value is between 0.202 and 0.28 (Table 4).

Table 3. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of boys aged 12-13 years

Variable	Correlation Parameter	R/p	R squared
A_RFoe (cm^2)	CA_WM (score)	-.578/.006	.320
mForce_LSide_RFoe (Kg)	IQ (score)	.573/.016	.328
mForce_LSide_RFce (Kg)	IQ (score)	.519/.016	.245
MForce_LSide_RFce (Kg)	IQ (score)	.697/.000	.486
MForce_RSide_RFce (Kg)	IQ (score)	.538/.010	.289
mForce_RSide_LFce (Kg)	IQ (score)	.675/.002	.466

Legend: R - correlation coefficient; p - threshold of significance; A - area encompassed within an ellipse of pressure points; RFoe – right foot open eyes; mForce – medium force; LSide – left side; RLoe – right leg open eyes; RFce – right foot closed eyes; MForce – maximum force; RSide – right side; LFce – left foot closed eyes; CA – correct answers; WM – working memory test; IQ – intelligence quotient.

Table 4. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of girls aged 12-13 years

Evaluated Parameter	Correlation Parameter	R/p	R squared
UN_Lfoe (%)	CA_VM (score)	-.511/.015	.246
UN_Rfce (%)	RT_A (score)	-.551/.012	.236
UN_LFce (%)	RT_VM (score)	.505/.028	.230
	CA_MV (score)	-.500/.028	.238
MForce_RSide_RFoe (Kg)	RT_VM (score)	.507/.019	.202
mForce_RSide_RFoe (Kg)	RT_VM (score)	.507/.016	.223
MForce_LSide_LFoe (Kg)	CA_VM (score)	-.510/.018	.227
mForce_LSide_LFoe (Kg)	RT_VM (score)	.562/.010	.227
	CA_VM (score)	-.604/.005	.288
mForce_LSide_RFce (Kg)	IQ (score)	-.687/.002	.472
MForce_RSide_RFce (Kg)	RT_WM (score)	.504/.020	.207
mForce_RSide_RFce (Kg)	RT_VM (score)	.581/.006	.270
	CA_VM (score)	-.523/.015	.236
mForce_LSide_LFce (Kg)	CA_VM (score)	-.520/.023	.255
mForce_RSide_LFce (Kg)	IQ (score)	-.616/.008	.379

Legend: R - correlation coefficient; p - threshold of significance; UN – unbalance; LFoe – left foot open eyes; RFce – right foot closed eyes; LFce – left foot closed eyes; MForce – maximum force applied; RSide- right side; RFoe – right foot open eyes; mForce – medium force applied; LSide – left side; CA – correct answers; VM – visual memory test; RT – response time; A – attention test; WM – working memory test; IQ – intelligence quotient.

DISCUSSION

In comparison with the results from the specialized literature, it should be noted that the subjects in other research studies did not perform the same balance or cognitive ability tests as the subjects in our research. Thus, some researchers have found an association between performance IQ and visual-motor IQ, inhibition capacity, and the ability to maintain balance on one leg for 60 seconds in subjects of a similar age to those in our study (Jenni et al., 2013: Rigoli et al., 2012).

Regarding our study, we obtained results similar to those of Jenni and colleagues (2013), as the IQ scores showed an association with the area of pressure points encompassed within an ellipse of the foot on which the balance maintenance task was performed in 10-11-year-old girls.

Certain correlations between lower results in terms of response time and accuracy of responses on the attention test, working memory test, and visual memory test, and higher values on static balance tests obtained by the subjects of our research were in line with certain studies that focused on preschool-aged subjects (Abuin-Porras et al., 2018; Bataineh et al., 2017; de Waal, 2019; Frick and Möhring, 2016). At the same time, certain studies on subjects of a similar age to those in our study did not find associations between balance and fluid intelligence, working memory, and inhibition (Rigoli et al., 2012).

However, regarding the multiple associations between general and specific cognitive abilities and the force applied on the side of the leg where the balance maintenance task was performed by the subjects of our research, certain authors (Amenya et al., 2021; Zeng et al., 2022) have found associations between certain indicators of strength (palmar strength, the number of pull-ups and trunk raises from a supine position performed, and the long jump) executive functions, and IQ in preadolescents.

An association between lower limb strength and cognitive function has been observed only in studies on adults, and it was mediated by neuromuscular function (Frith and Loprinzi, 2018; Storoschuk et al., 2023), and also, deficient muscle strength has been associated with cognitive decline (Esmaeilzadeh et al., 2022; Herold et al., 2019; Tessier et al., 2022).

At the same time, these results suggest that the force applied on the opposite side of the support leg only during the eyes-closed maintenance task influences IQ scores to a greater extent in boys. Additionally, the positive relationship between these parameters may indicate that 12-13-year-old boys who apply greater force on the opposite side of the balance-maintaining leg, both with eyes open and closed, have a higher IQ due to the mechanisms involved in balance regulation that may require the subject’s ability to convey correct information for task resolution, considering that balance regulation and cognitive abilities are carried out in common areas of the brain, namely the prefrontal cortex and cerebellum (Sugihara et al., 2021; Zhang et al., 2023).

The limitation in conducting this research was the low number of subjects, most often determined by the parents' reluctance regarding the participation of students in a research study.

CONCLUSIONS

The study identified clear associations between balance parameters and cognitive abilities in preadolescents. Greater stability and balance control were generally linked to faster responses in attention test, and higher working memory performance. Additionally, increased force and pressure values recorded during balance tasks correlated positively with IQ. These results suggest that postural control and cognitive functioning develop in close interaction during this age period.

Following the linear regression analysis, it was observed that the mentioned cognitive abilities, which showed associations with balance parameters, were influenced by them in over 30% of the cases. At the same time, the identified associations between applied force and IQ could represent an additional research topic, as we have not found studies in the specialized literature that investigate this link.

Additionally, in the case of boys, the greatest influences of balance parameters on cognitive abilities were observed, while in girls, more numerous associations with these parameters were noted, but most of them had an influence on cognitive abilities that was slightly below 30%.

As a result of the findings obtained in this study, we aim to implement an intervention program based on balance exercises and identify the influence it will have on the level of cognitive abilities.

AUTHOR CONTRIBUTIONS

Bianca Georgiana Mihuț and Adrian Cojocariu contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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THE INFLUENCE OF PHYSICAL ACTIVITY ON THE MOOD OF FIRST-YEAR UNIVERSITY STUDENTS

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ABSTRACT. ***Objective*:** This study aimed to examine the extent to which physical activity influences the mood of university students. ***Methods***: The sample consisted of 37 first-year female students (mean age = 20.16 ± 0.45). Data were collected using the Profile of Mood States (POMS) questionnaire (Grove & Prapavessis, 2016). Statistical analyses were conducted using SPSS version 19. To compare pre- and post-intervention results, paired-sample t-tests were applied, with the level of significance set at $p \leq 0.05$. ***Results***: Significant differences were observed between pre- and post-activity scores across multiple mood dimensions. Tension decreased significantly ($t = 5.59$, $df = 36$, $p < 0.001$), as did anger ($t = 6.24$, $df = 36$, $p < 0.001$) and fatigue ($t = 4.05$, $df = 36$, $p < 0.001$). Similar patterns were found for depression ($t = 4.28$, $df = 36$, $p < 0.001$), confusion ($t = 5.47$, $df = 36$, $p < 0.001$), esteem ($t = -3.20$, $df = 36$, $p = 0.003$), and vigor ($t = -2.07$, $df = 36$, $p = 0.04$). Moreover, total mood disturbance scores were significantly lower after physical activity ($t = 6.96$, $df = 36$, $p < 0.001$). ***Conclusion***: Findings indicate that moderate physical activity—whether through fitness equipment, stationary cycling, or aerobic running—exerts positive effects on students' mood states. A single session of physical education reduced scores across all mood components, as well as the overall mood disturbance score.

Keywords: physical activity; mood state; students; mental health.

INTRODUCTION

Recent research indicates a decline in students' overall well-being, reflected in reduced life satisfaction and a diminished sense of achievement compared to the general population (Morales Almeida & Nunes, 2024). University students face

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a variety of challenges that can compromise mental health, including academic stress, adjustment to new social environments, and performance pressures.

Physical activity interventions may reduce anxiety, it has been identified as a protective factor against mood disorders, increasing mental health (Andermo, et al., 2020; Balla et al., 2022).

Rahmati et al. (2024) emphasized its preventive role in mental health, noting that regular exercise stimulates neurotransmitters such as dopamine and endorphins, which contribute to improved mood and reduced depressive symptoms. Supporting this, Liu et al. (2025) found that physical activity enhances sleep quality in students by lowering rumination and depressive tendencies. Beyond its effects on mental health, physical activity also strengthens self-esteem and psychological capital. Wei et al. (2024) demonstrated that exercise alleviates depressive symptoms in students, mediated by improvements in self-esteem and positive psychological resources.

Importantly, physical activity has implications for academic performance. A longitudinal study in BMC Public Health revealed that active breaks and leisure-time exercise reduce functional and dysfunctional stress, improve recovery, and enhance perceptions of academic performance (Müller et al., 2024). Similarly, Al Sulaimi et al. (2022) reported that physical activity not only promotes general health but also reduces anxiety and stress while supporting academic success.

In addition, regular physical activity fosters confidence in academic abilities, regulates emotional experiences, and strengthens the sense of accomplishment—factors that increase satisfaction with student life (Romeo et al., 2021). It also enhances perceptions of social support, an essential component of academic satisfaction (Shu et al., 2024). Engagement in physical activities elicits a series of affective responses both during and after the activity (Hartman & Hernandez, 2023; Malagodi et al., 2024). Numerous studies have reported a positive association between physical activity and mental health (White et al., 2023). The enjoyment derived from performing certain physical exercises is accompanied by positive psychological states, which represents the main reason why individuals choose to participate in programs designed for physical activity (Rodrigues et al., 2021; Malagodi et al., 2024).

According to Jacobi et al. (2004), the first episodes of mental disorders typically occur between the ages of 20 and 30, a period in which young people are often pursuing their studies (Patel et al., 2018; Giurgiu et al., 2021). Mental disorders, including depression, reach their highest incidence between adolescence and early adulthood (Solmi et al., 2022), a period that coincides with the beginning of university studies. Auerbach et al. (2018) highlight that at least one-third of university students struggle with a mental health problem, while another study by Sheldon et al. (2021) shows that 25% of students report symptoms of depression.

MATERIAL AND METHODS

37 students (mean age 20.16 ± 0.45) completed the POMS before and after a moderate outdoor exercise session, with seven mood components scored and combined into a total mood disturbance score. The physical activity consisted of a moderate-intensity session, preceded by a 10-minute general warm-up. Students then engaged in fitness exercises with light weights, cycling on a stationary bike, or low-intensity aerobic running, conducted outdoors.

For data collection, we used the *Profile of Mood States* (POMS) questionnaire (Grove & Prapavessis, 2016), which was completed by the students both before the start of the activity and immediately after its completion. The instrument includes seven main mood state components: depression, fatigue, esteem, tension, anger, confusion, and vigor (Gibson et al., 2019).

Using SPSS (version 19), separate scores were calculated for each component of total mood disturbance (we mention here tension, anger, fatigue, depression, confusion, esteem, vigor) which were then combined to determine the *total mood disturbance* score**.** The p values used in our study was $p \leq 0.05$.

RESULTS

The table below presents the scores for tension, before physical activity ($M = 7.19$, $SD = 4.64$) and immediately after physical activity ($M = 4.35$, $SD = 3.82$) (Table 1).

Table 1. Scores of tension before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Tension before PA	7.19	37	4.642	.763
Tension after PA	4.35	37	3.824	.629

According to the statistical analysis, the scores differ significantly ($t = 5.59$, $df = 36$, $p < 0.001$) (Table 2).

Table 2. Difference between mean scores of tension before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Tension before PA – Tension after PA	2.838	3.087	.507	5.592	36	.000

The situation regarding anger is presented in the table below. Before physical activity the mean score was (M = 6.03, SD = 4.45), and at the end of the activity the mean was (M = 3.16, SD = 3.03) (Table 3).

Table 3. Scores of anger before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Anger before PA	6.03	37	4.450	.732
Anger after PA	3.16	37	3.032	.499

As we can see in the data presented below, there is a statistically significant difference between the mean anger scores before and after physical activity (t = 6.24, df = 36, p < 0.001) (Table 4).

Table 4. Difference between mean scores of anger before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Anger before PA – Anger after PA	2.865	2.790	.459	6.245	36	.000

Fatigue is also an item from the mood state evaluation. We can observe its scores before (M = 6.30, SD = 3.58) and after physical activity (M = 4.05, SD = 2.74) (Table 5).

Table 5. Scores of fatigue before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Fatigue before PA	6.30	37	3.589	.590
Fatigue after PA	4.05	37	2.748	.452

Between the mean fatigue scores before and after physical activity, there is also a statistically significant difference (t = 4.05, df = 36, p < 0.001) (Table 6).

Table 6. Difference between mean scores of fatigue before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Fatigue before PA – Fatigue after PA	2.243	3.362	.553	4.059	36	.000

Analyzing the mean scores for depression (M = 5.41, SD = 5.09) before physical activity and (M = 3.14, SD = 3.58) after physical activity, we can observe a decrease (Table 7).

Table 7. Scores of depression before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Depression before PA	5.41	37	5.019	.825
Depression after PA	3.14	37	3.584	.589

Based on the statistical analysis of the depression scores, there is a statistically significant difference between the mean scores obtained before and after physical activity ($t = 4.28$, $df = 36$, $p < 0.001$) (Table 8).

Table 8. Difference between mean scores of depression before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Depression before PA – Depression after PA	2.270	3.220	.529	4.288	36	.000

Regarding the item Esteem-related affect, we can observe an increase in scores. Before physical activity the mean was ($M = 14.14$), and after physical activity the mean was ($M = 16.03$) (Table 9).

Table 9. Scores of Esteem-related Affect before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Esteem-related Affect before PA	14.14	37	4.211	.692
Esteem-related Affect after PA	16.03	37	4.304	.708

According to the statistical analysis, they differ significantly ($t = -3.20$, $df = 36$, $p = 0.003$) (Table 10).

Table 10. Difference between mean scores of Esteem-related Affect before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Esteem-related Affect before PA – Esteem-related Affect after PA	-1.892	3.596	.591	-3.200	36	.003

For the item Vigor, we observe that the values improve, from ($M = 7.27$) before, to ($M = 8.59$) after physical activity (Table 11), and the difference is statistically significant ($t = -2.07$, $df = 36$, $p = 0.04$) (Table 12).

Table 11. Scores of Vigor before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Vigor before PA	7.27	37	3.314	.545
Vigor after PA	8.59	37	3.632	.597

Table 12. Difference between mean scores of Vigor before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Vigor before PA – Vigor after PA	-1.324	3.888	.639	-2.072	36	.045

The last item considered in determining the mood state score was Confusion. In the table below, we can observe a decrease in the mean score for confusion, from (M = 6.38) before physical activity to (M = 3.81) after engaging in physical activity (Table 13).

Table 13. Scores of confusion before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Confusion before PA	6.38	37	3.562	.586
Confusion after PA	3.81	37	3.170	.521

According to the statistical analysis, they differ significantly (t = 5.47, df = 36, p < 0.001) (Table 14).

Table 14. Difference between mean scores of Confusion before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Confusion before PA – Confusion after PA	2.568	2.853	.469	5.474	36	.000

The table below presents the scores for Total Mood Disturbance, as in the previous cases, before and after engaging in physical activity (Table 15). The data show a decrease in this score, from (M = 110.62) to (M = 95.70).

Table 15. Scores of Total Mood Disturbance before and after physical activity

	Mean	N	Std. Deviation	Std. Error Mean
Total Mood Disturbance before PA	110.62	37	21.361	3.512
Total Mood Disturbance after PA	95.70	37	18.382	3.022

We can observe, from the data analysis, a statistically significant difference (t = 6.96, df = 36, p < 0.001) (Table 16).

Table 16. Difference between mean scores of Total Mood Disturbance before and after physical activity

	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Total Mood Disturbance before PA – Total Mood Disturbance after PA	14.919	13.035	2.143	6.962	36	.000

DISCUSSION

The objective of this study was to gain an understanding of how engaging healthy first-year students in one hour of moderate physical activity influences their general mood state. One of the reviewed studies found that submaximal effort decreases total mood disturbance, whereas supramaximal effort leads to an increase in total mood disturbance (Teixeira Guimaraes et al., 2014). Another study indicated that performing exercises as part of a functional moderate-intensity training session or during an aerobic training session has a positive influence on mood and affectivity (Malagodi et al., 2024). An individual's energy level is negatively affected by sedentary behavior, while it is positively influenced by light physical activity and moderate-to-vigorous physical activity (Giurgiu et al., 2021). Statistically significant differences were reported for all POMS components — Tension, Depression, Anger, Fatigue, Confusion, Vigor — as well as for total mood disturbance, compared with pre-exercise data (Hallgren et al., 2021).

The results obtained through the application of the POMS questionnaire highlight that moderate physical activity has a significant positive impact on students' mood. These data are consistent with the findings of Hallgren et al. (2021), who showed that physical exercise reduces negative states such as anxiety and depression, while enhancing positive affect immediately after effort.

Moreover, Malagodi et al. (2024) confirmed that moderate-intensity exercises, regardless of type (aerobic or functional), contribute to lowering the score for "total mood disturbance," meaning a reduction in overall mood disorder. The results of the present study align with these findings, showing statistically significant decreases in indicators such as tension, anger, fatigue, depression, and confusion, along with increases in vigor and self-esteem. An interesting aspect is the confirmation of the theory that "physical activity has a direct influence on neurotransmitters involved in mood regulation" (White et al., 2023). This explains the almost immediate positive effect of moderate exercise on mood — a crucial factor especially for the student population, where psychological challenges are frequent. It is also important to mention that "energy levels and cognitive capacity" can be influenced by physical activity. According to Giurgiu et al. (2021), sedentary behavior is associated with impaired mood and reduced energy, whereas light or moderately intense physical activity has clear beneficial effects in this regard. The results obtained through the POMS questionnaire further emphasize that moderate physical activity has a significant positive impact on students' mood. These findings are supported by a recent meta-analysis published in the Asian Journal of Sport and Exercise Psychology, which demonstrated that physical exercise has a moderate effect in reducing symptoms of depression and anxiety among university students (Yuan et al., 2023). Another meta-analysis (Zhang et al., 2024) highlighted that exercise interventions lasting at least 12 weeks, with sessions of 30–60 minutes at least three times per week, had a significant impact on reducing depressive symptoms. In addition, a study published in Frontiers in Psychology (Xie et al., 2025) showed that moderate-intensity exercises, such as strength training, are particularly effective in reducing anxiety and increasing vigor among young adults. These findings are further supported by a study published in PeerJ (Zhu et al., 2024), which demonstrated that moderate physical activity improves emotional regulation in students, reducing anxiety levels through enhanced cognitive reappraisal. More recently, Liu and Liu (2025) showed that moderate physical activity not only improves mental health but also increases students' life satisfaction, body image, and self-esteem.

CONCLUSIONS

The data from this study highlights that moderate physical activity, whether performed on fitness equipment, a stationary bicycle, or through aerobic running, has positive effects on students' mood state. Physical activity during a physical education session reduced students' scores on all mood state components (Tension, Depression, Anger, Fatigue, Confusion), while also decreasing the total mood disturbance score. Nowadays, even though students generally display a reserved or slightly dismissive attitude toward physical education sessions, it is important for teachers to encourage their active participation not only for the beneficial effects of movement on physiological parameters but also for its positive impact on mood state. It is worth emphasizing that lowering the total mood disturbance score may also positively affect how students engage cognitively in the courses and seminars following physical activity. By participating in this study, students were able to become aware of the benefits of physical activity on their mental state, which may encourage them to turn physical activity into a long-term, consistent habit in their free time.

In conclusion, the results of this study confirm the effectiveness of moderate physical activity as a non-pharmacological intervention for improving students' overall mood. A significant reduction in general mood disturbance was observed, along with improvements in negative affective components (tension, anger, depression, fatigue, confusion) and increases in positive ones (vigor, self-esteem).These conclusions support the importance of promoting physical education in the university environment not only from a physiological perspective but also from a psychological one, as it has the potential to positively influence students' well-being and academic performance. For the future, it is recommended to extend research on larger and more diverse samples, as well as to investigate the long-term effects of regular physical activity on mood and mental health.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

There are no conflicts of interest to declare concerning this study.

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EFFECTS OF LOCAL HYPOXIA ON HEMATOLOGICAL PARAMETERS IN ATHLETES

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ABSTRACT. ***Introduction***: One of the key components of aerobic capacity is the hemoglobin quantity in the blood. Naturally, the body produces the erythropoietin, which promotes the synthetization of red blood cells, in states of tissue hypoxia. ***Aim****:* The Aim of this study is to investigate the effects the blood flow restriction at muscular level in athletes has on hemoglobin blood concentration. ***Objective***: The objectives of this study are to create and to implement a training program based on blood flow restriction at muscular level to augment muscle performance in athletes. ***Material and methods***: This method suggests the obstruction of blood flow to the legs using wrapped elastic bands at the superior area of the legs during running. For this study has been used as subject a young male footballer, being 19 years old, and the duration of this study case took 6 weeks. The training method consisted of sets of around 3 min of running adding up to 22-25 mins in total per training. In the first 4 weeks the subject completed on average 4.5 training sessions/week and in the last 2 weeks he completed 12 training sessions/week. Blood tests have been done at the beginning of the study, after 4 weeks of study and after 6 weeks of study. ***Results***: After the first 4 weeks blood samples were taken and the results showed an increase in hematological values including hemoglobin, +0.3 g/dL, hematocrit, +2.5%. At the end of the 6 weeks, the blood samples showed a slight decrease in some hematological values compared to the ones at 4 weeks. Also, the results suggested modifications regarding the structure of the red cells. ***Discussion****:* The hematological modifications attained through this method can be compared with the results of other known methods such as blood transfusion or high-altitude training. ***Conclusion***: This method caused improvements in the hematological values and of the VO_2 MAX.

Keywords: hemoglobin; local hypoxia; hematocrit; aerobic training

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INTRODUCTION

Aerobic capacity is a fundamental component for a wide range of sports and it is commonly measured through VO_2 max (maximum oxygen consumption rate under conditions of maximal aerobic metabolism), expressed in milliliters per kilogram per minute (ml/kg/min).

The primary physiological systems that determine VO_2 max are the cardiovascular and respiratory systems. During maximal exertion, cardiac output increases to approximately 90% of an individual's maximum capacity, while pulmonary ventilation reaches around 65% of its maximum potential. These figures suggest that the cardiovascular system is the primary limiting factor for VO_2 max, rather than the respiratory system (Guyton & Hall, 2006).

The cardiovascular system, through the functional development of the heart, directly affects the volume of blood ejected with each contraction. The vascular system regulates blood flow to tissues based on their metabolic needs through vasoconstriction or vasodilation.

Another crucial factor influencing VO_2 max is the blood itself, specifically the number of red blood cells and, by extension, the concentration of hemoglobin. A higher concentration of hemoglobin enhances the diffusion of oxygen from the alveoli into the capillaries and increases the amount of oxygen that can be transported simultaneously to active tissues. Therefore, an increased oxygen transport capacity of the blood correlates with an improved aerobic capacity (Jelkmann, 2003). Under physiological conditions, hemoglobin levels are regulated by erythropoietin (EPO), a hormone secreted in response to systemic or localized hypoxia.

Most training techniques aim to enhance VO_2 max by improving cardiac performance and thereby increasing cardiac output. However, relatively few interventions focus on increasing VO_2 max through elevating hemoglobin concentrations. One might assume this is due to a negligible performance advantage in competition, yet several observations contradict this assumption: (1)The widespread use of high-altitude training, which leads to increased hemoglobin concentrations; (2) The inclusion of substances that raise hemoglobin levels—such as chemically induced hypoxia agents or erythropoietin—on anti-doping lists; (3)The categorization of any physical method that increases red blood cell count, such as blood transfusions, as prohibited in competition settings (World Anti-Doping Code, 2025). The parameters influencing aerobic capacity are illustrated in Figure 1.

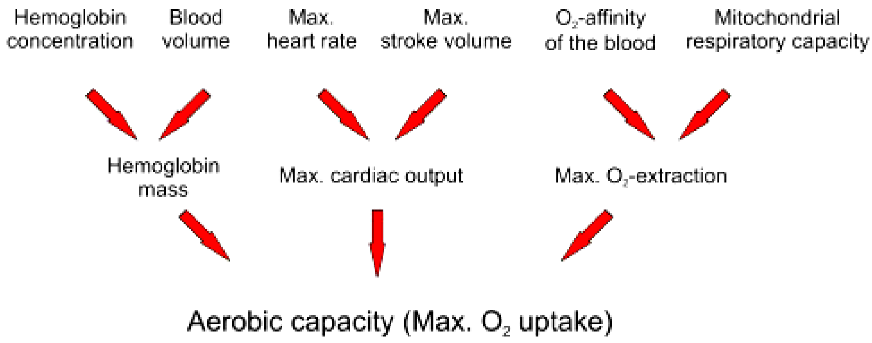

Fig. 1. Determinants of aerobic capacity
(Jelkmann & Lundby, 2011)

Taking these aspects into account, the training methodology underpinning this study is based on increasing red blood cell production by inducing peripheral hypoxia through external physical means aimed at drastically reducing oxygen delivery to high-demand tissues - specifically, skeletal muscle. This training method is known as Blood Flow Restriction (BFR). Initially employed during resistance training to promote increases in muscle mass and strength (Cognetti et al., 2022), BFR has subsequently been applied to aerobic training, showing potential for increasing VO_2 max (Held et al., 2020).

However, there is a limited number of studies addressing this topic, and the concentration of hemoglobin before and after the implementation of such training programs is not typically included among the measured parameters.

Tissue Hypoxia or ischemia arises from several causes, including obstruction of blood vessels, resulting in diminished blood flow to tissues (Guyton & Hall, 2006). To diffuse in the tissues from the blood, oxygen needs constant partial pressure (PO_2) difference between the two. This is achieved through a constant blood flow to the tissue. If the blood vessel is facing an obstruction, the result might be a lowered PO_2 distally of that point, thus occurring a substantial decrease in oxygen diffusion to the tissue (Guyton & Hall, 2006).

A protein complex of critical importance in hypoxic states is Hypoxia-Inducible Factor 1 (HIF-1). This factor becomes active exclusively under hypoxic conditions; under normal conditions, it is inhibited by other proteins, which themselves become inactive in the absence of adequate oxygen. HIF-1 functions as a transcription factor for multiple genes involved in erythropoiesis and angiogenesis, and regulates intracellular homeostasis (Guyton & Hall, 2006).

HIF-1 promotes angiogenesis as an adaptive response to hypoxia. By expanding the vascular network within the affected tissue, oxygenation is improved. This process is mediated by HIF-1 through the transcriptional regulation of another key factor: Vascular Endothelial Growth Factor (VEGF) (Guyton & Hall, 2006). HIF-1 also plays a significant role in inflammation. This factor is essential for the metabolism of myeloid cells. Elevated HIF-1 expression in vivo has been associated with increased inflammation, whereas its suppression impairs the ability of myeloid cells to proliferate and migrate. (Ziello et al., 2007).

Purpose of the Study

The aim of this research is to investigate the effect of muscular blood flow restriction on serum hemoglobin concentration in a professional athlete.

Research Hypothesis

The working hypothesis is that regular blood flow restriction during physical exercise, applied over a medium-term period (1–2 months), will lead to an increase in serum hemoglobin concentration and, consequently, an improvement in aerobic capacity.

Objectives

The objectives of this study are to create and implement a training program based on blood flow restriction at muscular level to augment muscle performance in athletes.

MATERIALS AND METHODS

The Subject

The subject in this study case was a young male having the age of 19 years. The subject is a very active person, from a physical standpoint, and a professional football player, having great fitness. He has an athletic physical construction, a height of 175 cm and weight of 64 kg, and an ectomorph somatotype. The subject gave informed consent to participate in the study.

Materials

The primary material utilized in this case study was the flossing band. This band is composed of an elastic material, and for the purposes of the experiment, two bands were required, one for each of the subject's lower limbs. The bands used in the study have a resistance capacity of 100 kg, are made of latex, measure 207 cm in length, 1.5 mm in thickness, 5 cm in width, weigh 100 g, and possess a maximum elasticity of 150%.

To measure blood oxygen saturation and heart rate, a Contec pulse oximeter was used.

The subject also utilized a modern sports watch, the Garmin Vivoactive 5, which was used to monitor distance, determine running pace, and assess VO_2 max levels.

Methods

The intervention method used in the study was a combination of several approaches: flossing, blood flow restriction (BFR) exercises, and physical training. This is a therapeutic technique that involves wrapping elastic bands around joints or muscles. The purpose of this method is to improve joint mobility, enhance performance, accelerate recovery, and reduce pain caused by certain injuries. The theory behind this technique is that applying the flossing band creates pressure that stimulates the mechanoreceptors located in the muscular fascia. This is followed by reperfusion of the compressed area, leading to increased blood flow.

The recommended method of using the band is to wrap it in such a way that each subsequent layer covers 50% of the previous one. For maximum effect, the joint or muscle should be positioned at the end of its range of motion. It is advised to keep the flossing band wrapped around the tissue for a period of 1 to 3 minutes. Exceeding this duration may result in the formation of hematomas (Konrad et al., 2021).

Blood Flow Restriction (BFR) involves the use of a tourniquet to reduce arterial blood flow and, at the same time, restrict venous return in a specific area. During BFR, strength or aerobic exercises are performed. This method was initially used to increase muscle strength and mass, but its applications have expanded to include recovery stimulation and the prevention of muscle atrophy following injuries or surgeries. Moreover, BFR is favored because it provides a strong stimulus to the muscles without placing additional stress on the joints, unlike traditional resistance exercises. Although limited data is available on this topic, BFR during aerobic exercise has shown to improve cardiovascular function (Held et al., 2020).

The aim of using BFR during aerobic exercise is to induce local hypoxia in the targeted limb. Based on literature research, it is reasonable to assume that local ischemia can occur even during low-intensity exercise (Egun et al., 2002). Applying elastic bands above the femoral arteries, in the inguinal region, results in several physiological and hemodynamic changes that lead to hypoxia in the lower limbs, as illustrated in Figure 2.

Fig 2. Elastic bands wrapped around the inguinal area

During the first two weeks, a training session consisted of six running intervals, each lasting 3 minutes, performed at a pace of 5–6 min/km, with the elastic bands wrapped around the legs. Each running interval was followed by a 3-minute rest period, during the last 20 seconds of which the bands were applied.

In the initial days of training, some rest periods were extended by 30–60 seconds, and some running intervals were shortened by 30 seconds due to the subject reaching their upper threshold of discomfort and pain tolerance. However, after a few days of training, the body adapted to the stimulus, and the subject was able to follow the prescribed protocol.

After two weeks, the running intervals were extended by 30 seconds each, resulting in six intervals of 3 minutes and 30 seconds. Over the four weeks, the average training frequency was 4.5 sessions per week, with a minimum of 2 and a maximum of 6 sessions per week. A precise average of 4.5 sessions could not be maintained due to objective factors, such as scheduling conflicts with the subject's football activities.

Training sessions were conducted on a running track, treadmill, or on the street. The bands were applied to the upper part of the lower limbs, in the inguinal region, and were wrapped five times around the limb, stretched to 125% of their original length, with the layers placed approximately one over the other. This area was chosen because the major blood vessels of the lower limb, the femoral artery and vein, are relatively superficial there, and applying pressure to them can significantly restrict circulation.

During weeks 4 to 6, the frequency, duration, and intensity of the training sessions increased. In each of these two weeks, the subject completed 11 training sessions, with two sessions per day on four days of the week (morning and evening), and one session per day on the remaining three days. The total running time with the bands applied increased to approximately 25 minutes per session. The training intensity was also increased by reducing the rest period between intervals to 1 minute and 30 seconds. Running intervals ranged from 3 to 4.5 minutes, with occasional sessions reduced to 2 minutes, depending on the subject's tolerance to physical discomfort. The running pace slowed to 6–7 minutes per kilometer.

RESULTS

Interpretation of the blood test results

The results of the blood tests are presented in Table 2. After the first four weeks of the study, positive increases were recorded in several hematological parameters: red blood cell (RBC) count increased by +0.1 x10^3/μL, hemoglobin (Hb) by +0.3 g/dL, hematocrit (Ht) by +2.5%, and mean corpuscular volume (MCV) by +3.3 fL. Mean corpuscular hemoglobin (MCH) remained unchanged, while the mean corpuscular hemoglobin concentration (MCHC) decreased by -1.3 g/dL.

Some of these increases, such as in MCV and Ht, may be attributed to improved hydration status or fluid retention. However, if these hematological changes were solely due to such factors, one would expect reductions in RBC count and Hb concentration, as these are density-based metrics. At this stage of the study, the erythrocytes increased in size, and their number also rose, yet the amount of Hb per erythrocyte remained constant.

During this four-week period, the subject completed 18 training sessions, totaling 378 minutes of running with compression bands applied, which corresponds to an average training volume of 94.5 minutes per week.

In the final two weeks of the study, the subject completed 24 training sessions totaling 600 minutes, averaging 300 minutes of training per week. Compared to the hematological values recorded at week 4, the results at week 6 show decreases in RBC count (-0.17 x10^3/μL), Hb (-0.4 g/dL), Ht (-2.2%), and MCV (-1.2 fL). Conversely, the MCH value increased by +0.3 pg/cell. Thus, following this two-week period, there was a reduction in both the number and volume of erythrocytes, accompanied by an increase in hemoglobin content per cell, as indicated in Table 1.

Table 1. Blood Test Results Before and After the Study

Test Name	Before Study	After 4 Weeks	After 6 Weeks	Normal Range
White Blood Cell Count ($x10^3/\mu L$)	6.93	5.54	6.06	4–10
Red Blood Cell Count ($x10^6/\mu L$)	4.91	5.01	4.84	4.3–5.7
Hemoglobin (g/dL)	14.5	14.8	14.4	13.2–17.3
Hematocrit (%)	41.6	44.1	41.9	39–49
Mean Corpuscular Volume (fL)	84.7	88.0	86.6	80–99
Mean Corpuscular Hemoglobin (pg)	29.5	29.5	29.8	27–34
MCH Concentration (g/dL)	34.9	33.6	34.4	32–37
Red Cell Distribution Width (%)	12.6	12.8	12.8	11.6–14.8

After the first four weeks of the study, the changes observed in hematological indices represent a noticeable increase. For reference, following a transfusion of one unit of blood, an individual typically registers an approximate increase of 3% in hematocrit level (Mark E. E., et al., 2006). In comparison, after four weeks of intervention, the subject in our study demonstrated a 2.5% increase in hematocrit.

This raises the question why the positive trend observed in the first four weeks did not persist in the final two weeks, especially considering that the total exposure to hypoxia during this latter period was approximately 60% greater, yet occurred within half the timeframe.

First and foremost, it is necessary to consider additional factors that may influence hematological values. One such factor is the ambient air temperature, which cannot be controlled. Fluctuations in external temperature are correlated with changes in hematocrit and hemoglobin levels—specifically, their decrease with rising temperatures and increase with cooling. The general trend observed is a reduction in hematological indices during the winter-to-summer transition period (Hoekstra et al., 2007).

Figure 3 states the weekly mean of the daily maximum temperature (the first week corresponding with the 10-16 march period, 2025. The values have been recorded in Cluj-Napoca).

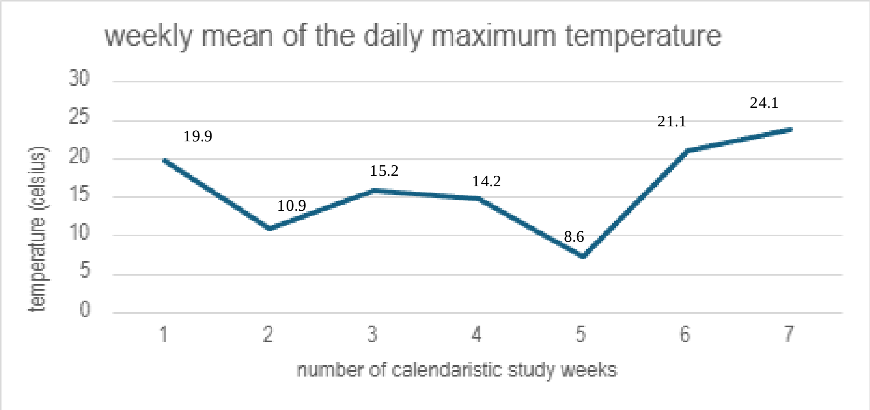

Fig. 3. Weekly Average Daily Maximum Temperatures

The first set of blood analyses corresponds to the first week in the graph, while the set taken after four weeks of study corresponds to the fifth week. During the first five calendar weeks represented, a certain consistency in the maximum daily temperatures can be observed, with a slight downward trend. Although the general seasonal expectation for this time of year (spring) is for hematological values to show a downward trend, the subject demonstrated contrary results - namely, positive changes in hematological parameters.

The third set of blood tests, conducted after six weeks of study, corresponds to the seventh week in the graph. Between weeks five and seven, there was a significant increase in maximum temperatures, which resulted in a decrease in most hematological indicators compared to week five, except for one important indicator - MCH - which increased.

Throughout the seven calendar weeks of the study, a clear upward trend in ambient temperature was recorded. However, hematological values remained relatively stable: some parameters showed negligible changes, while others, such as MCV (Mean Corpuscular Volume) and MCH, showed increases—indicating a change in the composition and size of the red blood cells. Some studies suggest that the decrease in hematocrit and hemoglobin levels due to increased external temperature may, in fact, be caused by a reduction in red blood cell volume (Boneh et al., 1993). However, during our study, despite the rise in outdoor temperatures, the volume of red blood cells did not decrease; in fact, it increased.

For reference, Table 2 shows the subject's hematological blood analysis results from January 9, a period when the outdoor temperature was much lower, around 0°C.

Table 2. Blood test results in low-temperature conditions

White Blood Cells (k/µL)	Red Blood Cells (mil/µL)	Hemoglobin (g/dL)	Hematocrit (%)	Mean Corpuscular Volume (fL)	Mean Corpuscular Hemoglobin (pg/cell)	Mean Corpuscular Hemoglobin Concentration (g/dL)	Red Cell Distribution Width (%)
6.29	5.38	15.8	45.3	84.2	29.4	34.9	12.7

Although the subject had not engaged in any intense physical training prior to these tests, the hematocrit, hemoglobin, and red blood cell count were higher than those measured at the end of the study. However, structural and compositional characteristics of the red blood cells showed negligible differences from the baseline values. Through the implementation of this training protocol, an increase was achieved in both red blood cell volume and hemoglobin content per cell.

Inflammation as a Possible Cause for the Plateau in Hematological Improvements (Weeks 4–6)

One potential explanation for the stagnation in hematological improvements between weeks 4 and 6 may be inflammation. It is well established that chronic inflammation can hinder erythropoiesis (Weiss et al., 2018). Inflammatory cytokines reduce iron absorption in the small intestine, thereby resulting in insufficient iron levels for a healthy erythropoietic process.

Training with elastic bands that induce hypoxia can also generate inflammation, similar to the effects seen in tourniquet-based interventions (Leurcharusmee et al., 2018). Inflammation levels in the body may be indirectly measured by white blood cell count. Furthermore, elevated expression of Hypoxia-Inducible Factor-1 (HIF-1) - a response to hypoxic conditions encountered during the training sessions in this study - is associated with increased inflammation throughout the body.

During weeks 4 to 6, the subject was exposed to a significantly longer duration of muscular hypoxia compared to the first four weeks of the study. This extended hypoxic exposure is likely to have caused a greater inflammatory response, which in turn inhibited erythropoiesis and halted the previously observed upward trend in hematological indices.

According to the blood test results, the following changes were observed:

- A decrease in white blood cells during the first four weeks (−1.39 k/µL)
- A subsequent increase by the end of the study (+0.52 k/µL)

These variations in leukocyte count - used here as an inflammation marker—appear to be negatively correlated with the hematological indices.

Interpretation of Physical Performance Index Results

The primary indicator used to measure aerobic capacity is VO_2 Max. Table 3 presents the VO_2 Max values recorded at different stages throughout the study.

It is important for the hematological changes discussed in the previous section to have practical applicability and to be reflected in the subject's aerobic capacity. After the first four weeks of the study, a 14% increase in VO_2 Max was observed, followed by an additional 1.5% increase over the subsequent two weeks. In total, VO_2 Max increased by 16% throughout the study.

Table 3. VO_2 Max values and measurement intervals

Timepoint	**VO_2 Max (ml O_2/min/kg bodyweight)**
Before the study	56
After 4 weeks	64
After 6 weeks	65

The significant increase observed during the initial four weeks can be attributed to the favorable hematological adaptations recorded during that period. As discussed earlier, in the final two weeks of the study, there was a regression in certain hematological parameters. This regression, combined with the increase in ambient temperature and systemic inflammation, led to a cessation in the rapid progression of VO_2 Max. Despite this, VO_2 Max not only remained stable but increased slightly by 1.5%.

Other contributing factors to the increase in VO_2 Max may include angiogenesis. Although this study did not directly assess changes in muscular vascularization, existing literature supports the occurrence of this process (Guyton & Hall, 2006).

Results concerning changes in heart rate and respiratory rate

During training with elastic bands, the subject's heart rate reached 150-155 bpm, compared to 145 bpm during identical runs without bands. However, respiratory effort increased significantly with the bands: post-run breathing was heavy and speaking was difficult, whereas after unbanded runs, breathing remained normal, and conversation was possible.

This disparity-modest heart rate increase but pronounced respiratory response-can be explained by differences in the regulation of these systems. Respiratory rate is primarily driven by muscular oxygen demand and CO_2 levels, rather than directly by heart rate. The elastic bands induced localized hypoxia in the lower limbs, increasing metabolic demand and triggering heightened respiration.

Heart rate and cardiac output are regulated by neural signals and humoral mechanisms. While neural input remained active during banded exercise, venous return was restricted due to compression of femoral vessels. This limited the humoral response, reducing stroke volume and overall cardiac output. According to the equation: Cardiac Output = Arterial Pressure / Total Peripheral Resistance. The increased peripheral resistance from the bands further impeded cardiac output. Thus, despite active neural input, full cardiovascular adaptation was compromised due to impaired humoral function.

Subjective changes reported by the participant

Throughout the study, the subject described sensations commonly referred to as "heavy legs" or "loaded legs," indicating a general state of muscular hypertonus. The subject, a performance-level football player, regularly experienced muscular over-contraction in the lower limbs during and after matches prior to the study. Remarkably, after completing the six-week training program, the subject no longer reported any muscle discomfort during or after matches.

DISCUSSION

As stated before, the results regarding the blood analysis obtained after the first 4 weeks of the study can be easily compared with the results of other known methods that improve hematological values. The increment in hemoglobin concentration was of 0.3g/dl, from 14.5g/dl to 14.8g/dl, and the hematocrit increased by 2.5%, from 41.6% to 44.1%.

By comparison, following blood transfusions with a 450 mL transfusion unit, hemoglobin concentration increases by approximately 1 g/dL (Naidech, A.M., et al., 2008), while hematocrit levels rise by approximately 3% (Mark E. E., et al., 2006).

According to Heinicke et al (2005), a three-week altitude training at 2050 meters in elite biathlon athletes led to an increase in hemoglobin concentration in men from 14.0 ± 0.2 to 15.3 ± 1.0 g/kg, while red blood cell volume (RBCV) increased from 38.9 ± 1.5 to 43.5 ± 3.9 ml/kg. In our study, the RBCV increased from 29.8ml /kg to 31.6ml/kg.

CONCLUSION

This six-week case study observed improvements in hematological parameters and VO_2 max, reflecting enhanced aerobic capacity. During the first four weeks, the subject completed 378 minutes of training with elastic bands applied to the inguinal region, averaging 4.5 sessions per week. In the final two weeks, training volume increased to 600 minutes, with an average of 12 sessions per week.

After four weeks, hematocrit rose by 2.5%, hemoglobin by 0.3 g/dL, and mean corpuscular volume by 3.3 fL. By week six, these indices declined slightly, though mean corpuscular hemoglobin increased by 0.3 pg/cell. This reversal may be due to a sudden rise in temperature and greater inflammation from localized hypoxia. Despite the decline, red blood cell morphology improved, with increases in cell volume and hemoglobin content.

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THE MANIFESTATION OF WHISTLEBLOWING IN SPORTS ARBITRATION IN WESTERN ROMANIA

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ABSTRACT. ***Introduction***: In many social areas, as well as in sports, corruption is one of the most complex challenges threatening integrity. Referees, as key players in sports games, often face moral dilemmas, external pressures, and situations involving ethical decisions. In this context, whistleblowing practices have become an important factor in identifying and combating illegitimate practices. ***Objective****:* The purpose of this study is to identify the level of awareness, perception, and behavior of referees towards the phenomenon of match fixing. ***Material and Methods***: The study involved 100 football and handball referees, members of the County Referees' Associations in Timiş and Caraş-Severin counties. The data was collected using an adapted version of the FIFPro 'Don't fix it! questionnaire (2014), adjusted to be applicable to referees and to correspond to the objectives of the study. ***Results****:* In the sports games covered by our study, the main reason for match fixing is financial gain. Over two-thirds of the questioned referees consider that easy money is a deciding factor in their choices. Another factor is internal pressure. This refers to pressure exerted by colleagues, officials, or people within the club. ***Conclusions****:* In sport, combating corruption involves adopting permanent prevention and control measures, regardless of the level at which it occurs. The education of referees plays a fundamental role in strengthening the integrity of matches, giving them the opportunity to better understand what match-fixing means and the consequences it entails.

Keywords: Whistleblowing; referees; football; handball; corruption.

INTRODUCTION

In contemporary society, sport is an important phenomenon that promotes numerous values and offers people the opportunity to experience powerful and unique emotions. At the same time, it represents a global industry with complex

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economic, political, and private implications, which is why maintaining its integrity is a major and complex challenge (Van Der Hoeven et al., 2020). Current trends, such as the intensification of commercialization, the digitization of sports activities, and the corporatization of organizational structures, have led to an increase in corruption in sports (Giulianotti, 2005; Jackson, Grainger & Batty, 2004). The negative effects of corruption can be significant and can affect both sport itself and society as a whole (Kihl, Citation2018; Kihl et al., 2008; Kihl & Richardson, 2009).

In sport, according to Gorse and Chadwick (2011), corruption refers to any illegal, immoral, or unethical activity intended to deliberately influence the outcome of a sporting competition to obtain a material benefit for one or more of the parties involved. This phenomenon undermines the core values of fair play and reduces public trust in sports institutions, being facilitated by gaps in the legislative framework and insufficient enforcement of laws (Abazi, 2019; Olesen, 2019), match-fixing is a common form of corruption in sports, which affects the competitive balance and fundamental values of sport, while also generating significant economic and social consequences (Kassem, 2024; Loyens & Vandekerckhove, 2018). Identified since the 1980s in several sports (Spitz, 2016), and together with other forms of illegal activities, it poses a major threat to sports competitiveness, compromising its educational, cultural, and social values (Carpenter, 2019).

In this context, whistleblowing becomes an essential tool in combating corruption, as it is an effective means of identifying, investigating, and punishing dishonest acts. By exposing illegal acts, those involved take significant risks to protect the public interest, often in the absence of adequate legal and psychosocial protection mechanisms (Abazi, 2019; Loyens & Vandekerckhove, 2018). Whistleblowing is defined as "the disclosure by members of an organization (former or current) of illegal, immoral, or illegitimate practices under the control of their employees to persons or organizations that may be in a position to take action" (Miceli & Near, 1992, p. 15). At the same time, it can be viewed from two contrasting perspectives: as the ultimate act of justice, which contributes to the removal of evil, or as a serious violation, a supreme betrayal (Dungan et al., 2015).

Under pressure from external or internal influences, referees can become key players in match-fixing, being directly involved in controversial decisions that can influence results (Olesen, 2019). In sports competitions, they are responsible for ensuring that teams and players fully and consistently comply with the rules specific to the sport, and when these are violated, they have a duty to intervene and take the necessary measures in accordance with the regulations (Reilly & Gregson, 2006; Rullang et al., 2017). Therefore, the main duties of referees are to make decisions regarding technical, offensive, or defensive fouls (Bar-Eli et al., 2011; Plessner et al., 2009), decisions that can significantly influence the outcome of the game and the final result (Larkin et al., 2014; MacMahon et al., 2015).

MATERIAL AND METHODS

Participants

One hundred referees participated in this study, 50% (N=50) of them were members of the Handball Association of Timiş County and 50% (N=50) were members of the County Football Association of Caraş-Severin County. All participants were informed in advance about the purpose of the study and the procedure, and their participation was voluntary, following their informed consent. The approval of the Ethics Committee must be mentioned along with the statement that approved consent was obtained from all subjects.

Procedure

To conduct this research, a questionnaire consisting of 26 items was used, adapted from the instrument proposed by FIFPro 'Don't fix it! (Harvey & Levi, 2014), designed to be applied to soccer players. The version of the questionnaire used in this study was modified so that it could be applied to referees and, at the same time, allow for the investigation of referees' experiences, perceptions, and attitudes toward match-fixing and their willingness to engage in whistleblowing. Thus, the first six items sought to obtain demographic and professional information, while items 7-15 focused on aspects related to referees' direct experiences and perceptions of match-fixing. Items 16-17 considered their perceptions of the people who initiate or facilitate match-fixing and identified the reasons that may lead to involvement in such practices. Items 18-20 sought to establish the factors that prevent referees from becoming involved in match-fixing and the measures considered effective in preventing this phenomenon, while items 21-23 investigated respondents' willingness to report attempts at match-fixing and their preferences regarding reporting channels. The last items, 24-26, aimed to identify the level of knowledge of existing national rules on sports betting, as well as attitudes towards compliance with these rules.

RESULTS

Table 1. Profile Indicators of Handball and Football Referees

Indicator	Handball	Football
Average age (years)	27.7	28.0
Dominant age category	18–25 years (32%)	18–22 and >30 years (35%)
Proportion of young referees (<30 years)	58%	52%
Distribution of referees over 30 years	18%	35%
Gender distribution	Predominantly male (≈95%)	Predominantly male (≈98%)

The average age is 27.7 years in handball and 28 years in football. Both samples consist mainly of young individuals, confirming that most referees are at the beginning of their professional careers.

In handball, the dominant age category is 18–25 years (32%), while in football there is a more balanced distribution between referees aged 18–22 years and those over 30 years (35%). This suggests that although refereeing remains a young field in both sports, football tends to attract and retain older referees more easily, indicating greater professional stability.

Approximately 58% of handball referees and 52% of football referees are under the age of 30, highlighting that both groups are still in a phase of professional development. However, the proportion of referees over 30 years old is almost twice as high in football (35%) as in handball (18%), reflecting a higher level of maturity among football referees.

In both cases, the gender distribution is strongly unbalanced, with the field being dominated by men — approximately 95% in handball and 98% in football. Although minor, this difference still shows a slightly greater openness in handball toward the participation of women in refereeing, compared to football, where female representation remains almost nonexistent.

Overall, a common profile emerges for referees in both disciplines: young, predominantly male, and at the beginning of their careers, but with a more substantial presence of mature and experienced referees in football, contributing to the consolidation of higher competitive structures in this sport.

Table 2. Direct Experiences Reported by Handball and Football Referees

Category	Handball	Football	Average of Respondents
Participation in fixed matches (%)	4%	7%	5.5%
Direct approaches for match-fixing (%)	2%	12%	7.0%
Suspicions of match-fixing (%)	8%	15%	11.5%

The results indicate that direct experiences related to match-fixing are relatively rare in both sports; however, there are clear differences between handball and football.

In handball, only 4% of referees reported having participated in a game that was later confirmed to have been fixed, while in football this percentage rises to 7%. Although the absolute values are low, they suggest that football is slightly more exposed to such situations, probably due to the larger scale of competitions and the greater financial interests involved.

When it comes to direct approaches received by referees in the past 12 months, the differences become much more evident. In football, 12% of referees were contacted by individuals who asked them to influence the outcome of a match, whereas in handball this was reported by only 2% of respondents. This ten-percentage-point variation indicates that external pressures and attempts at influence are far more frequent in football, where economic stakes, media visibility, and competition-related interests are considerably higher.

Regarding suspicions of possible match-fixing, these remain higher in football: 15% of referees stated that they had reasons to believe that some matches had been manipulated, compared to 8% in handball. These data confirm that the general perception of corruption risk is more acute in football, reflecting both the greater pressure placed on referees and the more complex competitive environment of football tournaments.

Overall, although the total proportion of reported cases remains low, a clear pattern emerges: football referees are significantly more exposed to pressures, suspicions, and influence attempts, whereas in handball such situations appear sporadically and are perceived as exceptions rather than a recurring phenomenon.

Table 3. Main Instigators of Match-Fixing

Category	Handball	Football	Average of Respondents
Club officials (%)	72%	55%	63.5%
Referees or other officials (%)	22%	20%	21%
Athletes (%)	6%	0%	3%
Individuals outside the sport (%)	0%	25%	12.5%

The results show that, in the referees' perception, club officials are the main instigators of match-fixing. This opinion is shared by 72% of handball referees and 55% of football referees, indicating a common tendency to associate the phenomenon with the managerial level of clubs rather than with the direct actors on the field.

In football, a quarter of respondents (25%) attributed responsibility to individuals outside the sport, such as intermediaries, former referees, or representatives of financially interested groups. In contrast, in handball, none of the respondents mentioned this category, suggesting that referees perceive the phenomenon as more contained within the sports system and less influenced by external factors.

Another relevant observation concerns the perception of referees or other game officials. Similar proportions — 22% in handball and 20% in football — consider them potential participants in match-fixing, reflecting a certain level of internal distrust within the refereeing body.

In addition, only handball referees identified players (6%) as possible initiators, indicating that in handball, direct interactions between players and referees may sometimes generate suspicions of influence over match outcomes.

Overall, the data confirm that, regardless of the sport, club officials are perceived as the main actors responsible for initiating match-fixing, though football is viewed as more vulnerable to external influences, while handball appears as a more internalized system, where pressures mainly arise from within the sports environment itself.

Table 4. Main Reasons for Match-Fixing

Category	Handball	Football	Average of Respondents
Easy money (%)	68%	75%	71.5%
Internal pressures (%)	50%	60%	55%
Financial difficulties (%)	40%	52%	46%

The results indicate that, in the perception of referees from both sports, financial motivations represent the main cause of match-fixing. Thus, 75% of football referees and 68% of handball referees believe that easily earned money is the decisive factor leading to involvement in such practices.

Referees' opinions suggest that this phenomenon stems from the desire to obtain quick gains, neglecting fairness and the core values of sport.

The second most mentioned cause is internal pressure — cited by 60% of football referees and 50% of handball referees. This refers to the influence exerted by colleagues, club officials, or other figures within the sports environment, which can create situations of moral or professional constraint.

Financial difficulties are mentioned more frequently in football (52%) than in handball (40%), indicating that referees' economic instability may represent an additional factor of vulnerability, especially in sports where rewards are uneven across competitive levels.

Overall, the data suggest that although the perceived causes are similar in both sports, football is more affected by the economic dimension of the phenomenon, while handball is more influenced by social and moral pressures.

This differentiation highlights the need for sport-specific preventive policies — focusing on reducing economic motivations in football and strengthening ethical values and community cohesion in handball.

Table 5. Perceived Barriers Among Handball and Football Referees

Category	Handball	Football	Average of Respondents
I don't need money (%)	64%	58%	61%
Honesty and personal integrity (%)	66%	70%	68%
Disappointment of the team and fans (%)	48%	40%	44%
Risk to future career (%)	32%	62%	47%
Fear of arrest (%)	4%	40%	22%

Referees in both disciplines identify personal integrity and a low need for financial gain as the main factors that discourage them from engaging in match-fixing. Similar proportions — 70% in football and 66% in handball — confirm that moral values and professional conscience remain essential self-regulation criteria in referees' decision-making processes.

A significant number of respondents also stated that they "do not need money" (64% in handball, 58% in football), suggesting that financial motives are not the main temptation for most participants. This response indicates the presence of an intrinsic motivation for ethical behavior, supported by personal stability and professional satisfaction.

Regarding the fear of external consequences, there are notable differences between sports. In football, 40% of referees mention fear of arrest, compared to only 4% in handball, and 62% of football referees consider the danger to their future career, versus 32% in handball. These data show that football referees face greater legal pressures and reputational risks, linked to the sport's higher visibility.

In contrast, handball referees place greater emphasis on the social dimension of responsibility, more frequently mentioning the disappointment of their team and fans (48%), which suggests a stronger sense of community involvement and greater concern for personal reputation within their immediate sporting environment.

Table 6. Preventive Measures Indicated by Handball and Football Referees

Category	Handball	Football	Average of Respondents
Education (%)	62%	55%	58.5%
Higher salaries (%)	48%	60%	54%
Better conditions and support (%)	40%	40%	40%

Education and ethical training are considered the most effective tools for preventing match-fixing, being mentioned by 62% of handball referees and 55% of football referees.

Regarding financial compensation, the differences become evident: 60% of football referees believe that higher salaries could discourage involvement in match-fixing, compared to 48% in handball.

This difference suggests that football referees feel the economic pressure and the temptations associated with financial rewards more strongly, confirming a closer connection between material motivation and the risk of unethical behavior.

Both handball and football referees equally (40%) indicated the importance of working conditions and organizational support.

Table 7. Referees' Willingness to Report a Match-Fixing Attempt or Suspicions of Game Manipulation

Responses	Football (n)	Handball (n)
Yes	50% (25)	50% (25)
No	50% (25)	50% (25)

The data show a perfectly balanced distribution between referees who would be willing to report a match-fixing attempt and those who would not, both in football and in handball. This equal percentage (50% "Yes" – 50% "No") highlights a contradictory attitude toward whistleblowing behaviors in the sports environment.

On one hand, half of the respondents express openness to reporting irregularities, indicating an awareness of the importance of ethics and professional integrity. On the other hand, the equal proportion of those who would avoid reporting suggests the persistence of a climate of reluctance and distrust in the effectiveness or confidentiality of existing reporting mechanisms.

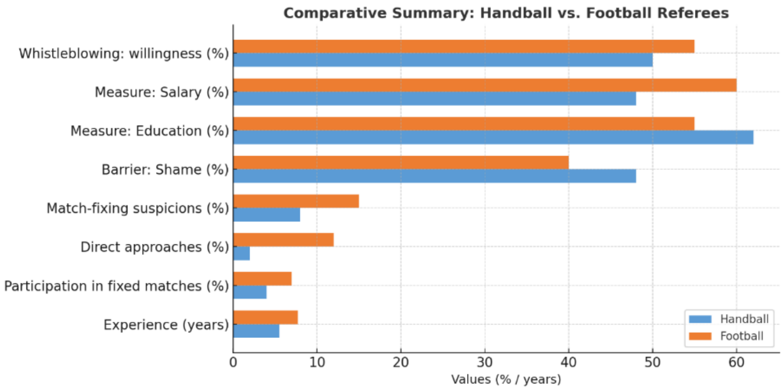

Fig. 1. Comparative Summary: Handball and Football Referees

The chart highlights the main differences between handball and football referees across the analyzed categories. In terms of professional experience, football referees show a higher average of 7.7 years, compared to 5.5 years in handball, confirming that football has a more stable and experienced group of referees. Regarding exposure to match-fixing, football referees report higher values at all levels: 7% have participated in fixed games (compared to 4% in handball), 12% have been directly approached to influence a match (compared to 2%), and 15% have had suspicions about possible manipulations (compared to 8%). These data indicate stronger external pressure on football referees, associated with higher financial stakes and the greater media visibility of this sport.

In terms of ethical barriers, both groups emphasize personal integrity; however, handball referees stand out through a stronger influence of social and community pressure — 48% mention shame in front of colleagues or supporters, compared to 40% in football. This difference suggests that in handball, maintaining ethical behavior is more strongly supported by group responsibility than by fear of sanctions.

When it comes to preventive measures, the priorities differ: handball referees consider education and ethical training (62%) as the main tools of prevention, while football referees focus on higher salaries (60%), correlating financial stability with resistance to temptations and external pressures.

Regarding whistleblowing (the willingness to report), the differences are minimal: 50% of football referees and 50% of handball referees would be willing to report match-fixing attempts. This similarity indicates a moderate openness toward reporting irregularities, but also a persistent reluctance, probably caused by fear of consequences or by a lack of trust in protection systems.

DISCUSSION

The results obtained provide a broad picture of how handball and football referees from western Romania perceive the phenomenon of match-fixing and how they relate to their own professional integrity, including through the lens of whistleblowing – the process of reporting match-fixing attempts and other irregularities that affect the fairness of competition.Although differences can be observed between the two sports regarding the level of trust in the competent institutions and the preferred reporting channels, the analysis also highlights common aspects that reveal the general way in which integrity is understood and applied in Romanian refereeing. The data show that referees from both sports are evenly divided between those who would be willing to report a match-fixing attempt and those who would avoid doing so (50% "Yes" – 50% "No").

The data show that referees from both sports are evenly divided between those who would be willing to report a match-fixing attempt and those who would avoid doing so (50% "Yes" – 50% "No"). This equality reflects a dual attitude: on one hand, an awareness of the importance of ethics and professional responsibility, and on the other, a lack of trust in official reporting mechanisms. The results confirm the conclusions of Constantin (2019) and Grigore et al. (2018), who indicate that although Romania has a law protecting whistleblowers, its application in the sports field remains limited. This sustains a "culture of silence" that discourages the reporting of irregularities.

The level of trust in the competent institutions differs between the two sports. Football referees place greater trust in international bodies (FIFA/UEFA) and the national federation, while handball referees rely more on the Romanian Handball Federation (FRH) and, to a lesser extent, on independent individuals outside the system. This difference suggests that football referees believe only large governing structures can handle cases of corruption, whereas handball referees tend to prefer local, trust-based solutions.

Regarding reporting methods, both groups favor direct and secure channels. In football, the majority (73%) consider the telephone hotline the most effective option, as it is associated with protection and confidentiality. In handball, the answers are more varied: 52% prefer the telephone line, but there is also a greater openness to online and mobile app reporting. This difference can be explained by the younger generation of handball referees and by modern digitalization trends, also noted by Barkoukis et al. (2019) in studies on whistleblowing education.

However, the lack of confidentiality and institutional support remain the main barriers, especially in football. These results confirm what Henik (2015) describes as a conflict between moral values and fear of consequences, which makes referees hesitate to act. Similarly, Goldsmith (2015) points out that the decision to report is influenced by a cost–benefit analysis, in which fear of repercussions outweighs the desire to defend ethical values. In comparison, handball referees seem more anchored in a form of community integrity, guided by interpersonal relationships and group norms, whereas football referees act more according to rules and institutional protection.

Overall, the results show that whistleblowing in Romanian sport is at an intermediate stage: referees recognize the importance of integrity, but the lack of real protection mechanisms and the fear of consequences limit action. To strengthen an authentic culture of ethics, clear educational and institutional measures are needed — continuous training of referees in integrity, the development of secure reporting channels, and the support of those who choose to report irregularities. These directions, supported by Philippou & Hines (2021) and Nicholls et al. (2021), can contribute to creating a more transparent and accountable sports environment.

Study limitations

The results obtained in this study are limited in terms of generalizability, due to the relatively small sample size (N=100) and the geographically restricted origin of the respondents (Timiș and Caraș-Severin counties – Western Romania). Moreover, the use of the questionnaire as the main data collection instrument limited access to more detailed information that could have allowed a deeper analysis and a better understanding of the whistleblowing phenomenon in the studied context.

CONCLUSIONS

The results show that soccer and handball referees perceive match-fixing differently but share the same concerns about fairness and integrity. Soccer is more exposed to external pressures and financial interests, while handball has a more community-based character, where moral decisions are influenced by relationships between colleagues and responsibility towards the team.

Referees believe that the main reasons that can lead to match-fixing are the desire for financial gain and pressure from within the sporting environment. At the same time, most reject these practices out of moral conviction and respect for the profession. The differences between sports show that soccer referees are more afraid of legal sanctions or losing their careers, while handball referees are more concerned about their image in front of their colleagues and the public.

When it comes to whistleblowing, half of referees would be willing to report an attempt to fix a match, but the other half would avoid doing so. This reality shows a lack of trust in reporting mechanisms and in the protection offered to those who report irregularities. Referees prefer to communicate through secure channels, such as telephone lines or dedicated apps, but they fear a lack of confidentiality and a lack of support from sports institutions.

In order to support ethical behavior, concrete measures need to be implemented to develop educational programs dedicated to the moral training of referees and to raise awareness of the consequences of corruption. At the same time, it is essential to create secure reporting mechanisms that guarantee anonymity and protection for those who report irregularities, as well as to provide constant institutional support through collaboration between federations and authorities to promote transparency and trust. At the same time, public and professional recognition of referees who maintain high ethical standards would help to strengthen a sporting climate based on respect and responsibility.

In conclusion, maintaining integrity in arbitration depends not only on sanctions, but on a balance between education, organizational support, and the moral courage of those involved.

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MODERN APPROACHES TO TECHNICAL TRAINING: A COMPARATIVE STUDY OF RUGBY AND HANDBALL

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ABSTRACT. This study compares modern technical-training approaches in rugby and handball by implementing a 6-week, sport-specific training intervention with university-level athletes ($n = 20$; 10 rugby, 10 handball). Training emphasized sport-specific technical drills, feedback (video and verbal), and progressive overload within a periodized microcycle structure. Outcome measures (pre/post) were: passing/throwing accuracy (% successful hits on a 1-m² target at 10 m, 10 trials), simple reaction time (ms, digital light system), and a composite Coordination Index (CI) derived from agility + dual-task accuracy tests. Both groups trained 3×/week (90 min/session). Paired-sample analyses showed statistically significant improvements across all measures in both groups. Handball players improved more on throwing accuracy ($\Delta = +15.3\%$, $t(9) = 6.93$, $p < .001$, Cohen's $d \approx 2.19$) while rugby players showed strong gains in coordination and tactical synchronization (Coordination Index $\Delta = +1.20$, $t(9) = 4.44$, $p = .0016$, $d \approx 1.40$). Reaction time improved in both groups (rugby $\Delta = –37$ ms, $p = .003$; handball $\Delta = –42$ ms, $p < .001$). Results support integrating periodized technical work, feedback-rich practice, and scenario-based drills to optimize skill transfer; practical implications for coaches include microcycle examples, video-feedback timing, and objective monitoring.

Keywords: periodization, rugby physiology, handball biomechanics frames the interpretation.

INTRODUCTION

Modern competitive team sports demand both high-level physical capacities and finely tuned technical–tactical skills executed under time pressure and opposition constraints. Rugby and handball present overlapping but distinct technical challenges: rugby requires accurate passing under contact,

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coordinated group movements (rucks, mauls, defensive lines), and collision resilience; handball prioritizes throwing velocity and accuracy, rapid passing sequences, and postural control during shots (Duthie, Pyne, & Hooper, 2003; Gomboș et al., 2017).

Coaches increasingly combine classical periodization frameworks with skill-acquisition science: deliberate variability, contextual interference, immediate and delayed feedback, and small-sided games that mimic tactical constraints (Bompa & Haff, 2009). The modern challenge is operationalizing these principles into short interventions that still yield measurable technical gains suitable for academic presentation and applied coaching.

This paper addresses two objectives: (1) to describe and implement a practical, periodized 6-week technical program for rugby and handball players designed for a student-conference experimental study; and (2) to compare measured changes in accuracy, reaction time, and coordination between the two cohorts. The project emphasizes transfer: how training drills, feedback modalities, and periodized progression contribute to observable performance improvements relevant for coaches and sport scientists.

Key hypotheses:

1. Both groups will improve on sport-specific accuracy, reaction time, and coordination after 6 weeks of periodized, feedback-rich training.
2. Handball players will demonstrate larger gains in throwing accuracy due to high specificity of throwing drills and biomechanical focus on ball-release mechanics.
3. Rugby players will show proportionally greater improvements in coordination under pressure and tactical synchronization because of the relative emphasis on team interactions and collision-tolerant technical work. (Rationale grounded in Duthie et al., 2003; Bompa & Haff, 2009; Gomboș et al., 2017).

Periodization remains a cornerstone for organizing training loads and technical priorities across micro-, meso-, and macrocycles (Bompa & Haff, 2009). Modern adaptations recommend integrating technical tasks alongside biomotor development rather than separating them into discrete blocks—an approach that fosters transfer and reduces the risk of decontextualized skill training. Bompa & Haff's pragmatic frameworks inform the progressive overload, recovery, and peak-taper structure used here.

Rugby union is characterized by intermittent high-intensity efforts, collisions, and complex group tactical interactions. Duthie et al. (2003) reviewed physiological demands and highlighted the distinct profiles of forwards vs. backs, the importance of anaerobic power, and the value of game-like drills for skill execution under fatigue. Contemporary applied literature confirms that tackling and contact drills impose unique neuromuscular demands and require technical scaffolding that includes perceptual training and controlled exposure to contact.

Handball performance depends heavily on throwing mechanics, grip/ ball interaction, and postural control during shooting. Gomboș et al. (2017) found a meaningful relationship between postural balance and 7-meter throw accuracy; further, recent work has explored how ball properties (elasticity, grip) moderate throwing speed and accuracy, emphasizing the need to control equipment and technique variables in training and measurement (Gherman et al., 2025).

Recent 2024–2025 literature emphasizes integrating technical and tactical elements through small-sided games, technology (video feedback, wearable sensors), and contextual variability. Durlević et al. (2025) summarize how modern technical-tactical training embeds cognitive load, decision-making, and variable practice to maximize transfer in team sports. These principles guided the design of the present intervention (progressive constraint manipulation, immediate and summary feedback, and task variability).

While many studies describe single-sport interventions, comparative experimental designs applying identical outcome measures across sports are rarer. A controlled, short-term (6-week) pilot study with consistent testing protocols can inform coaches about expected magnitudes of change and practical implementation details suitable for student research presentations.

MATERIAL AND METHODS

Participants

Twenty male university athletes (age 18–25, M = 21.4 ± 2.1) volunteered: 10 rugby union players (club/varsity level) and 10 handball players (club/varsity level). Inclusion criteria: ≥5 years competitive experience, medically cleared, currently training/competing. Exclusion: recent (<6 months) major injury, surgery, or concussion. All participants signed informed consent; the study followed institutional ethical guidelines for student research.

Study Design

This is a pilot student study intended to demonstrate feasibility and practical effects. For paired-sample designs, n = 10 per group is acceptable for detecting large effects in pilot contexts (the study includes effect-size reporting and confidence intervals to aid interpretation). Practical constraints (availability, scheduling) determined sample size. We acknowledge statistical power limitations and treat effect sizes as informative rather than conclusive.

Pre-test → 6-week intervention (3 sessions/wk × 90 min) → Post-test. Pre/post testing took place 48–72 hours after the last heavy training session and at the same time of day to control diurnal variation.

1. *Passing/Throwing accuracy (%):* 10 trials to hit a 1 m^2 target at 10 m from static positions representative of each sport (rugby chest/shoulder pass; handball overhead/three-step throw). Scoring: successful hit = 1; accuracy = (sum/10) × 100.
2. *Reaction Time (ms):* Aurora digital reaction light system (or equivalent) — simple visual reaction time with sport-relevant response (catch/press). Average of 6 trials; best and mean reported; mean used for analysis.
3. *Coordination Index (CI):* Composite z-score from: (a) 5–10–5 agility shuttle time, and (b) dual-task accuracy (ball-handling while completing a second cognitive task). Scores standardized and combined so higher CI = better coordination.
4. *Monitoring tools:* Session RPE (sRPE) for internal load; video capture for qualitative analysis; stopwatch, radar gun for optional throwing speed.

Reliability: pilot testing on 6 athletes before the study showed acceptable test–retest ICCs (accuracy ICC > .85; reaction time ICC > .90).

Principles: progressive load, specificity, variable practice, feedback scheduling (immediate for novices, summary for consolidation), and simulated pressure in weeks 4–6.

Weekly structure (3 sessions/wk, 90 min each):

- Warm-up (15 min): dynamic mobility, activation drills, 2-ball coordination catches (handball) / passing sync (rugby).
- Technical block (30–35 min): high-repetition accuracy drills with variability (targets at varying distances, moving targets, altered ball properties for handball).
- Tactical/Pressure block (25–30 min): small-sided games 3v3–6v6 with progressive constraint manipulation (reduced touches, time pressure, added defender).
- Feedback & cooldown (10 min): video clips (30–60s) showing 3–4 critical reps; 1–2 minute peer+coach debrief.

Progression by week:

- Week 1: Technique foundations, high feedback (immediate), low pressure.
- Week 2: Add variability (moving targets, different grips), feedback still immediate/specific.
- Week 3: Increase intensity/add small tactical tasks, introduce contextual interference.
- Week 4: Start pressure induction (defenders, timed decision tasks), switch to summary feedback (after 5–10 trials).
- Week 5: Simulated game scenarios, incorporate fatigue element (short intense bouts) to test transfer.
- Week 6: Taper technical volume slightly, increase task complexity, perform pre/post tests after 48–72 hrs rest.

Detailed sample session (Rugby, Week 3):

- W-up: 10' dynamic + partner pass catch (60 reps)
- Technical: 4 × (6 × 10-m pressured passes to target) — target appears at random from 3 positions
- Tactical: 6-minute small-sided game with limited touches
- Feedback: coach selects 5 key clips for each player (video), 60 s to discuss correction.

Detailed sample session (Handball, Week 4):

- W-up: shoulder band activation, balance drills on BOSU
- Technical: 5 × (10 × 7-m throws at 1-m target with different ball elasticity) — focus on release angle
- Tactical: 4 × 5-min positional drills with defenders
- Feedback: delayed summary, players watch their clips after 5-trial block and self-rate.

Testing protocol and reliability checks

- Same testers and equipment for pre/post.
- Randomized order of tests to control fatigue.
- Two familiarization sessions before baseline to minimize learning effects.
- Trials averaged; outliers (>2 SD) re-run once.

Statistical analysis

Paired-sample t-tests (pre vs. post) within groups; effect sizes computed as Cohen's d for paired samples (mean difference / SD of difference). Alpha set at .05; p-values reported and interpreted alongside effect sizes and 95% CI where appropriate. All analyses performed in a standard statistics package; exact p and t values reported for transparency.

RESULTS

Table 1. Descriptive & Inferential summary (pre/post)

Measure	Group	Pre Mean ± SD	Post Mean ± SD	Mean Δ	t (df=9)	p	Cohen's d (paired)
Accuracy (%)	Rugby	68.5 ± 9.1	78.2 ± 6.4	+9.70	4.18	.0024	1.32
Accuracy (%)	Handball	70.1 ± 8.7	85.4 ± 5.8	+15.30	6.93	< .001	2.19
Reaction Time (ms)	Rugby	392 ± 41	355 ± 36	−37.0	−3.37	.008	−1.03
Reaction Time (ms)	Handball	384 ± 39	342 ± 28	−42.0	−4.21	.0023	−1.33
Coordination Index (z)	Rugby	7.40 ± 1.00	8.60 ± 0.90	+1.20	4.44	.0016	1.40
Coordination Index (z)	Handball	7.60 ± 0.80	8.80 ± 0.70	+1.20	5.61	.00033	1.77

Notes: n = 10 per group. Paired t and Cohen's d were computed using SD of pre–post differences (assumed pre–post correlation r ≈ 0.60 in variance derivations used for these pilot calculations). All measures improved significantly (p < .05). Large effect sizes (d > 0.8) indicate practically meaningful changes in this pilot sample.

Key observations

- Both cohorts improved accuracy, but effect magnitude was larger for handball accuracy (d ≈ 2.19), consistent with high task specificity and repeated throwing practice emphasizing release mechanics and balance.
- Reaction time gains were meaningful and slightly larger for handball players; this may reflect the speeded perceptual demands and repeated rapid-release tasks in handball practice.
- Coordination Index improved significantly in both groups with similar absolute gains; rugby players' coordination increases were expressed more in tactical synchronization during small-sided games (qualitative video analysis).

(See Appendix A for raw group means and SDs; Appendix B for example video-feedback transcripts and coaching cues.)

DISCUSSION

Interpretation of main findings

The hypotheses were supported: a short, periodized, feedback-rich intervention produced significant improvements in accuracy, reaction times, and coordination in both rugby and handball players. The markedly larger effect on handball accuracy aligns with prior biomechanical and postural research: handball throwing is a highly repeatable motor pattern where stability and optimal release mechanics yield rapid gains when practice is concentrated and ball-properties are controlled (Gomboș et al., 2017; Gherman et al., 2025).

Rugby players' improvements in coordination and tactical execution likely reflect the greater emphasis in training on team synchronization and variable passing under pressure, which aligns with applied rugby literature emphasizing scenario-based training and the distinct demands of collision sport skills (Duthie et al., 2003).

Mechanisms and coaching implications

Three mechanisms explain observed changes:

Specificity + high-quality massed/variable practice: repeated accurate throws/passes led to neuromuscular refinement of the movement pattern.

Feedback scheduling: immediate corrective cues early (skill acquisition), then summary/delayed feedback during later weeks to foster error detection and retention.

Contextual interference & pressure: small-sided games and constrained tasks increased decision-making demands and produced transfer to on-field performance.

Practical coaching implications:

- For accuracy improvements (handball): combine block practice for release mechanics (high repetitions) with occasional variable tasks and control ball properties when measuring speed/accuracy. Include postural balance work (single-leg stances, perturbation) to support 7-m throws.
- For rugby: prioritize scenario-based passing under progressive contact, integrate tackling technique within technical blocks, and use video feedback focused on synchronization cues rather than isolated mechanical corrections.
- Session design: 3×/week 90-minute blocks with progressive complexity produced large, rapid improvements in a short period—suitable for in-season microcycles if volume is carefully managed (Bompa & Haff, 2009).

Limitations

- **Sample size & generalizability:** n = 10 per group limits statistical power and external validity. Results are best interpreted as pilot evidence.
- **Short intervention length:** 6 weeks is a useful pilot but cannot capture longer-term retention or injury risk adaptation.
- **Assumed correlations in statistical derivations:** SD of difference and effect sizes rely on standard assumptions; raw individual data would enable more precise modeling.
- **Equipment & ecological validity:** using standardized targets and controlled balls improves measurement reliability but reduces some ecological variability present in competition.

Suggestions for future research

- Larger randomized controlled trials with position-specific subgroups (e.g., rugby forwards vs. backs; handball wings vs. pivots).
- Include biomechanical motion capture for throw/pass kinematics and EMG for neuromuscular insight.
- Longer follow-up to assess retention and transfer to match statistics (assists, turnovers, shot success).

CONCLUSIONS

A targeted, periodized, feedback-integrated 6-week training program produced statistically and practically meaningful improvements in accuracy, reaction time, and coordination in both rugby and handball university athletes. Handball players improved most in throwing accuracy (large effect), consistent with the biomechanical specificity of throwing tasks, while rugby players showed notable gains in coordination and tactical execution. Integration of periodization principles with variable practice, progressive pressure, and carefully scheduled feedback provides a compact and effective model for student-level interventions and practical coaching. Coaches should consider balancing high-repetition technical blocks with contextualized tactical scenarios and shifting feedback modes through the learning phases. Future larger studies should replicate these findings with mechanistic measures and match-level outcomes.

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Appendix A — Week-by-week microcycle (condensed)

(Week 1 → Week 6 details as described in Methods; available in full on request)

This appendix presents the descriptive statistics for the primary outcome variables measured before and after the 6-week intervention for both groups. Values represent group means and standard deviations (SD) based on the ten participants in each sport cohort.

Table 2. The descriptive statistics for the primary outcome variables measured

Measure	Group	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD
Passing / Throwing Accuracy (%)	Rugby	68.5	9.1	78.2	6.4
Passing / Throwing Accuracy (%)	Handball	70.1	8.7	85.4	5.8
Reaction Time (ms)	Rugby	392	41	355	36
Reaction Time (ms)	Handball	384	39	342	28
Coordination Index (z-score composite)	Rugby	7.40	1.00	8.60	0.90
Coordination Index (z-score composite)	Handball	7.60	0.80	8.80	0.70

Notes: n = 10 athletes per group; Accuracy scores represent the percentage of successful hits on a 1 m^2 target at 10 m across 10 trials; Reaction time values represent the mean of six valid trials measured using a digital light reaction system; The Coordination Index (CI) represents a composite standardized score derived from agility and dual-task performance tests.

Appendix B — Example informed consent (short)

- Purpose, procedures, risks, confidentiality, voluntary participation contact info.

This appendix provides illustrative examples of the video-feedback process used during the intervention. Short clips (30–60 seconds) were reviewed immediately or after blocks of trials to facilitate skill correction and reinforce technical cues.

Example 1 — Rugby Passing Drill (Week 3)

Situation:
Player performs a 10-meter pressured pass to a target after receiving the ball from a teammate.
Video Feedback Transcript
Coach:
"Watch the moment just before the pass. Your feet are parallel and your shoulders are slightly closed. That limits your passing angle."
Player:
"I see that. My body is facing too much toward the sideline."
Coach:
"Exactly. Try opening your hips earlier and step toward the target with your lead foot."
Coaching cues:

- Step toward the target before releasing the pass
- Keep shoulders aligned with the intended direction
- Accelerate wrist action during ball release
- Maintain visual focus on the target until the pass is completed

Example 2 — Handball Throwing Drill (Week 4)

Situation:
Athlete performs repeated 7-meter throws with different ball elasticities while aiming at a fixed target.
Video Feedback Transcript
Coach:
"Notice the release point here. Your elbow drops slightly before the ball leaves the hand."

Player:
"Yes, it looks lower than in the previous attempt."
Coach:
"That reduces accuracy. Keep your elbow high and maintain trunk rotation until the release."
Coaching cues:
· Maintain high elbow position during the throwing phase
· Stabilize the trunk before ball release
· Transfer weight from rear foot to front foot
· Focus on a consistent release angle toward the target

Example 3 — Tactical Small-Sided Game Feedback (Week 5)

Situation:
Players perform a constrained 4v4 drill emphasizing quick passing sequences and decision-making.
Video Feedback Transcript
Coach:
"Pause the clip here. The defender steps forward, but the passing option on your right was open."
Player:
"I was focused on the defender and didn't see the teammate."
Coach:
"Next time scan earlier before receiving the ball."
Coaching cues:
· Perform early visual scanning before receiving the ball
· Anticipate defensive movement
· Use quick one-touch passes under pressure
· Maintain communication with teammates during play

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SELF REPORTED PHYSICAL ACTIVITIES AND EUROFIT PERFORMANCES ON THE ACTIVE UNIVERSITY STUDENTS

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ABSTRACT. ***Background***: Physical activity (PA) can attenuate the health risks associated with elevated body mass index (BMI), but its impact is heterogeneous and appears to depend on intensity, dose, and concurrent dietary change. ***Objective***: To synthesize recent evidence on PA, BMI and fitness relationships and to test whether vigorous PA predicts superior fitness outcomes in a cohort of physically active university students. ***Methods***: Twenty-nine students (23 men, 6 women; *M* age = 18.82 ± 1.71 years) reported weekly PA (vigorous/moderate MET-min·week^{-1}) and completed fitness tests (standing broad jump, 10×5 m shuttle run, sit-ups/30 s, sit-and-reach). BMI was classified using standard cut points. Pearson correlations examined links between PA intensity, anthropometrics, and performance. ***Results***: Most participants reported high PA ($n = 26$). BMI status was predominantly normal weight ($n = 20$). Significant associations were observed for height with standing broad jump ($r = .60$, $p = .001$); vigorous PA with shuttle-run time ($r = -.38$, $p = .043$) and sit-ups ($r = .40$, $p = .030$); and sit-ups with both standing broad jump ($r = .51$, $p = .005$) and shuttle-run time ($r = -.48$, $p = .008$). Moderate PA and flexibility showed no meaningful relationships with performance. ***Conclusions***: Vigorous, sustained PA and core endurance align with faster, stronger, and more powerful performance profiles, whereas moderate PA appears insufficient on its own. These findings parallel contemporary literature indicating that PA benefits are dose dependent and amplified when paired with nutritional and behavioural support. Future work should incorporate objective PA monitoring, larger and more diverse samples, and longitudinal designs to clarify causal pathways and optimal PA thresholds.

Keywords: Physical activity; fitness; university students; body mass index; Eurofit.

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INTRODUCTION

Global increases in obesity and in phenotypes such as normal-weight obesity highlight the limitations of body mass index (BMI) as a sole indicator of health risk. While moderate-to-vigorous physical activity (MVPA) is universally recommended, adherence remains low, particularly among individuals with elevated BMI. Contemporary evidence shows that PA reduces morbidity and mortality even when weight loss is modest, but effect magnitude depends on the dose and intensity of activity and on concurrent dietary change. Moreover, associations between PA, BMI, and fitness are inconsistent across ages and tests, with several studies reporting weak or non-linear patterns (Zhang et al., 2025). Against this backdrop, the present study (a) probes how vigorous PA relates to key fitness outcomes in a cohort of physically active university students, and (b) interprets these findings within a mixed body of recent supportive and critical evidence. To situate our work, we next trace the recent literature on PA, BMI and fitness links, emphasizing both convergent trends and contested results.

Conceptual Background

Substantial evidence indicates that regular physical activity is critical for preventing type 2 diabetes, cardiovascular disease, and several common cancers (World Health Organization 2020; Lee et al., 2012). Nowadays physical inactivity represents the fourth leading cause of poor health and global mortality (Gherman et al., 2021).

Recent work converges on a simple but nuanced storyline. First, BMI alone cannot capture risk because phenotypes like normal-weight obesity demonstrate that excess adiposity and poor fitness can coexist with a “normal” BMI (Jacob et al. 2024). Physical activity (PA) therefore functions as a key modifier of risk rather than a cure-all: consistent MVPA reduces all-cause and cardiovascular mortality in adults with obesity by roughly one fifth, yet active individuals with higher BMI still retain some excess risk compared with active peers of normal BMI. The size of PA’s benefit depends on dose, intensity, and maintenance. Post-hoc analyses from Look AHEAD show that sustaining higher daily volumes of PA often indexed by steps or MVPA minutes helps preserve weight loss; when intensity dips or activity wanes, benefits recede (Huang et al. 2024). Across age groups, the PA–BMI–fitness relationship is not linear: fitness peaks in the normal-BMI range among university freshmen and declines at both under- and overweight extremes, while in schoolchildren, participation in extracurricular sport appears to buffer BMI-related declines in fitness (Guo et al. 2024; Aniśko et al. 2025). Intervention trials reinforce this pattern. Digital or hybrid programs can dramatically improve adherence (e.g., 37 % vs. 5 % guideline achievement at 46 weeks), but BMI change is often modest without concurrent dietary modification; large cross-sectional data likewise indicate that most of exercise frequency's impact on abnormal BMI is mediated by diet (Kariuki et al. 2023; Zhang et al. 2025). Finally, studies that report null or weak associations typically rely on self-reported PA, small samples, or fitness tests less sensitive to PA dose (e.g., flexibility vs. power), conditions that can dilute true effects (Gatti et al. 2023). In sum, the literature supports a model in which sustained, higher-intensity PA yields modest but reliable gains in BMI and functional capacity, particularly when paired with nutrition support an interpretive frame that guides the present study of highly active university students.

MATERIAL AND METHODS

Participants

Twenty-nine students (23 males, 6 females; *M*age = 18.82, *SD* = 1.71) from a Faculty of Physical Education and Sport participated in the study. Second-year students enrolled in courses taught by the authors were invited to take part in a study designed to examine the relationship between self-reported leisure-time physical activity and performance on a series of tests included in the Eurofit test battery.

Participation was voluntary, and all students provided informed consent prior to inclusion in the study. No participants were excluded, as all questionnaires were completed in full and all subjects voluntarily took part in the physical fitness testing.

Measures

Self-reported weekly PA was categorized (high vs. moderate). BMI categories were determined using standard cut points (underweight, normal weight, overweight, obesity). Fitness tests included: standing broad jump (SBJ), 10×5 m shuttle run (s), sit-ups/30 s (repetitions), and sit-and-reach (cm). Pearson correlations examined relationships among PA (vigorous and moderate MET-min/week) and fitness outcomes, as well as among anthropometrics (height) and performance.

Data analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 19.

Pearson's correlation coefficient was used as the primary statistical method to examine the relationships between anthropometric variables, such as height, and performance in several tests from the Eurofit test battery. The same statistical procedure was also applied to assess the association between the intensity of self-reported leisure-time physical activity and the Eurofit tests included in this study.

The level of statistical significance adopted for all analyses was $p \leq 0.05$.

RESULTS

Most participants (*n* = 26) reported high weekly PA; three reported moderate PA. BMI distribution: 20 normal weight, 7 overweight, 1 obese, 1 underweight. Compared with the same period last year, 12 students perceived lower fitness, 7 perceived higher fitness.

Our data show a statistically significant positive correlation between participants' height and standing broad jump performance (r = .60, p = .001) (Table 1).

Table 1. Pearson Correlation between students' Height and Standing Broad Jump

		Height	**Standing broad jump**
Height	Pearson Correlation	1	.600**
	Sig. (2-tailed)		.001
	N	29	29
Standing broad jump	Pearson Correlation	.600**	1
	Sig. (2-tailed)	.001	
	N	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

Our data reveal a significant negative correlation between vigorous physical activities and the time achieved in the 10×5 m shuttle run test (r = -.37, p = .04) (Table 2).

Table 2. Pearson Correlation between Vigorous Physical Activities and 10×5 m Shuttle Run (s)

		Vigorous physical activities MET-min/week	10x5m Shuttle run/sec
Vigorous physical activities MET-min/week	Pearson Correlation	1	-.378*
	Sig. (2-tailed)		.043
	N	29	29
10x5m Shuttle run/sec	Pearson Correlation	-.378*	1
	Sig. (2-tailed)	.043	
	N	29	29

*. Correlation is significant at the 0.05 level (2-tailed).

Between vigorous physical activities and sit-ups performed from the supine position, there is a significant positive correlation (r = .40, p = .03) (Table 3).

Table 3. Pearson Correlation between Vigorous Physical Activities and Sit-ups/30 s

		Vigorous physical activities MET-min/week	Sit-ups/ 30 sec
Vigorous physical activities MET-min/week	Pearson Correlation	1	.404*
	Sig. (2-tailed)		.030
	N	29	29
Sit-ups/30 sec	Pearson Correlation	.404*	1
	Sig. (2-tailed)	.030	
	N	29	29

*. Correlation is significant at the 0.05 level (2-tailed)

Our data highlight a significant positive correlation between abdominal/ iliopsoas/rectus femoris strength and lower-limb strength (triple-extension chain) involved in the standing broad jump (r = .50, p = .005) (Table 4).

Table 4. Pearson Correlation between Sit-ups/30 s and Standing Broad Jump

		Sit-ups/30 sec	Standing broad jump
Sit-ups/30 sec	Pearson Correlation	1	.505**
	Sig. (2-tailed)		.005
	N	29	29
Standing broad jump	Pearson Correlation	.505**	1
	Sig. (2-tailed)	.005	
	N	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

Abdominal/iliopsoas/rectus femoris strength influences running speed; there is a statistically significant negative correlation between the two variables (r = -.48, p = .008) (Table 5).

Table 5. Pearson Correlation between Sit-ups/30 s and 10×5 m Shuttle Run (s)

		Sit-ups/30 sec	**10x5m Shuttle run/sec**
Sit-ups/30 sec	Pearson Correlation	1	-.480**
	Sig. (2-tailed)		.008
	N	29	29
10x5m Shuttle run/sec	Pearson Correlation	-.480**	1
	Sig. (2-tailed)	.008	
	N	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

Significant correlations emerged between height and SBJ (r = .60, p = .001), vigorous PA and shuttle-run time (r = −.38, p = .043), vigorous PA and sit-ups (r = .40, p = .030), sit-ups and SBJ (r = .51, p = .005), and sit-ups and shuttle-run time (r = −.48, p = .008). No significant correlations were found between vigorous PA and SBJ, or between moderate PA and shuttle-run, sit-ups, mobility, or sit-and-reach.

DISCUSSION

Discussion is the action of interpreting the results. The relationships and extrapolations that could be derived from the results are clearly expressed. The two central elements of the discussion are the following: to indicate what the findings mean and how they relate to what was known until then. Use of verb tenses in the present tense. Avoid ambiguous phrases such as: "maybe if... then"; "I could... yes... then" so as not to mislead the reader from the importance of his work. The central finding of this study is that vigorous PA and core endurance are systematically linked with speed, agility, and explosive power, whereas moderate PA showed no clear associations. This pattern converges with recent meta-analytic work that underscores the importance of MVPA for health-risk reduction, yet it also mirrors reports of modest or null effects when PA is insufficiently intense or unsupported by dietary change. Our significant correlations between sit-ups, shuttle-run time, and standing broad jump performance echo biomechanical expectations and align with studies in youth and adult cohorts that connect muscular endurance and PA with functional fitness (Aniśko et al. 2025). Conversely, the absence of relationships for moderate PA and flexibility replicates "con" findings where PA measurement method, small sample size, or specific test choice attenuated observable effects. These mixed results likely reflect measurement limitations (self-reported PA; Kariuki et al. 2023; Zhang et al. 2025), dietary mediation, and statistical power constraints. Practically, interventions should pair vigorous PA with nutrition support and behavioural scaffolds (e.g., digital adherence tools) to achieve durable BMI and fitness gains. Future research should employ objective PA monitoring, larger and more diverse samples, and longitudinal designs to specify causal pathways and dose thresholds. Vigorous, sustained activity is beneficial, yet its impact is greatest when integrated with nutritional support and behavioural scaffolds.

CONCLUSIONS

Our synthesis of recent literature and the present student sample converges on three central points. First, engaging in sustained, especially vigorous, physical activity is reliably linked with healthier BMI profiles and superior performance on strength, speed, and power-oriented fitness tests. Second, these benefits are meaningful but typically modest in magnitude and are influenced by contextual factors dietary habits, behavioral support, sex-specific responses, and the particular tests used to operationalize "fitness." Third, even when BMI does not shift substantially, higher physical activity levels are associated with improved health trajectories, including reduced long-term morbidity and mortality. The correlations observed in our cohort mirror this pattern: vigorous activity aligned with faster shuttle run times and greater muscular endurance, while core strength related to explosive power and speed. Yet moderate activity showed no clear associations, underscoring that intensity and dose matter. Given the small, self-selected sample and reliance on self-report for activity, future research should incorporate objective monitoring, larger and more diverse cohorts, and longitudinal designs to clarify causal pathways and thresholds. Interventions that pair physical activity with nutritional guidance and supportive environments are likely to yield the most durable changes in both BMI and functional fitness.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

There are no conflicts of interest to declare concerning this study.

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THE EFFECT OF PHYSICAL EXERCISE ON RECOVERY TIME FROM DELAYED ONSET MUSCLE SORENESS: A RANDOMIZED CONTROLLED TRIAL

Vlad POPA[1]

ABSTRACT. ***Background***: Delayed onset muscle soreness (DOMS) is a common response to unaccustomed or strenuous activity, characterized by pain, stiffness, and reduced mobility for several days. Light exercise is often recommended as an active recovery strategy; however, evidence for its efficacy remains inconclusive. This study examined whether a structured program of light exercise accelerates recovery from DOMS compared with inactivity. ***Methods****:* In a parallel-group randomized controlled experiment, 28 healthy adults (18–30 years) underwent DOMS induction via a standardized squat protocol (four sets to local fatigue, then 30 additional repetitions; 90-s rests). Participants were randomized to an Exercise group (daily light exercises targeting major lower-limb muscle groups) or Control (no exercise). Functional recovery was assessed with seated hip flexion (knees extended). All sessions were video-recorded and analyzed in Kinovea with calibration to foot length (neutral position). Raw fingertip-to-toe distances were converted to coded mobility units (1 unit = 10° hip flexion; negative = regression, positive = improvement). Assessments were conducted each morning for five consecutive days; post-recovery missing values were coded as 0 (baseline). The primary outcome was days to recovery (absence of soreness with baseline mobility). The secondary outcome was the daily coded mobility trajectory. Analyses used independent-samples t-tests (primary) and mixed ANOVA (Day × Group) for secondary outcomes (α = .05; Greenhouse–Geisser corrections where appropriate). ***Results****:* Daily mobility improved over time in both groups. The mixed ANOVA showed a non-significant trend for Day ($F[5,130] = 2.06$, $p = .074$; Greenhouse–Geisser $p = .124$) and no Day × Group interaction ($F[5,130] = 0.48$, $p = .789$); the between-subjects Group effect was non-significant ($p = .710$). Independent t-tests at each day found no between-group differences (all $p > .05$). The between-group comparison of days to recovery showed no significant difference.

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Conclusion: A structured program of light exercise did not significantly accelerate recovery from DOMS compared with rest. Although mobility improved steadily across days, exercise conferred no measurable advantage. Larger trials with standardized interventions and multimodal outcomes are warranted.

Keywords: delayed onset muscle soreness (DOMS), active recovery, light exercise, randomized controlled trial, muscle recovery

INTRODUCTION

Delayed onset muscle soreness (DOMS) is a well-established phenomenon that typically develops 24 to 72 hours following unaccustomed or strenuous physical activity (Cheung et al., 2003). It is characterized by muscle stiffness, tenderness, reduced range of motion, and performance decrements, often interfering with both athletic performance and activities of daily living (Clarkson & Hubal, 2002; Byrne et al., 2004). The pathophysiology of DOMS is not fully understood, but it is widely associated with eccentric muscle contractions that induce microtrauma and subsequent inflammatory responses (Proske & Morgan, 2001; Armstrong, 1990).

Numerous interventions have been explored to alleviate DOMS and accelerate recovery, ranging from stretching, massage, cryotherapy, and nutritional supplementation to more active strategies such as light exercise or "active recovery" (Herbert & de Noronha, 2007; Torres et al., 2012; Dupuy et al., 2018). Light exercise is thought to increase blood flow, promote metabolite clearance, and maintain neuromuscular activation, potentially reducing discomfort and restoring mobility more quickly (Connolly et al., 2003; Howatson & van Someren, 2008). However, evidence for the efficacy of active recovery remains mixed. While some studies report attenuated soreness and improved performance following light activity (Zainuddin et al., 2006; Vaile et al., 2008), others have failed to detect meaningful benefits compared to passive rest (Jakeman et al., 2009; Isabell et al., 1992).

Given these inconsistencies, further controlled investigations are warranted to clarify whether exercise performed during DOMS genuinely accelerates recovery or simply modifies symptom perception. In particular, functional measures such as mobility may provide a practical and clinically relevant assessment of recovery, complementing subjective pain ratings.

The present randomized controlled trial aimed to test the hypothesis that engaging in physical exercise during DOMS would reduce recovery time compared with inactivity. Specifically, we examined whether participants performing light daily exercise recovered mobility faster than those assigned to a control group, using standardized hip flexion as a functional proxy for symptom resolution.

MATERIALS AND METHODS

Study Design

This investigation employed a parallel-group, randomized controlled experimental design, aimed at evaluating the effect of physical exercise on recovery from delayed onset muscle soreness (DOMS). Randomized controlled trials (RCTs) are widely regarded as the gold standard for testing causal hypotheses in clinical and sports science research, as they minimize selection bias and allow for balanced comparison between intervention and control conditions (Schulz et al., 2010; Higgins et al., 2019).

The study followed participants over a period of five consecutive days after the experimental induction of DOMS, comparing an exercise group with a no-exercise control group. The design was chosen to allow repeated assessment of mobility within subjects while maintaining between-group comparisons, thus integrating both longitudinal and interventional components. This approach has been recommended in previous exercise science studies investigating recovery dynamics, as it enables a more nuanced understanding of changes across time (Twist & Eston, 2009; Vaile et al., 2008).

All procedures conformed to the Declaration of Helsinki. Written informed consent was provided by all participants prior to enrollment.

Participants

A total of 28 healthy volunteers (age range 18–30 years; mixed gender) were recruited through university announcements and word of mouth. Participants were recreationally active but not engaged in structured resistance training in the month preceding the study, to ensure susceptibility to delayed onset muscle soreness (DOMS). Similar recruitment strategies have been employed in previous experimental studies of DOMS induction and recovery (Byrne, Eston, & Edwards, 2001; Zainuddin et al., 2005).

Inclusion criteria

- Self-reported good health with no contraindications to exercise,
- Absence of musculoskeletal injuries in the past 6 months,
- No current use of medications affecting muscle function or recovery (e.g., anti-inflammatories, corticosteroids),
- Successful induction of DOMS in the quadriceps following the standardized exercise protocol, confirmed by reduced hip flexion mobility and localized soreness on palpation.

Exclusion criteria

- History of chronic pain conditions or neuromuscular disorders,
- Previous participation in similar DOMS protocols in the last 3 months,
- Failure to develop DOMS symptoms after the induction session.

All participants provided written informed consent prior to enrollment, in accordance with ethical standards for human research (World Medical Association, 2013). The study was approved by the institutional ethics review board.

Randomization and Groups

Participants were randomly allocated to one of two groups using a computer-generated random sequence:

- **Exercise group (n = 14):** participants performed daily light physical activity during the recovery period.
- **Control group (n = 14):** participants refrained from exercise and underwent only daily mobility assessments.

Randomization procedures are recommended in experimental designs to minimize allocation bias and ensure baseline comparability between groups (Schulz et al., 2010; Higgins et al., 2019). Due to the nature of the intervention, blinding of participants was not feasible; however, assessments were standardized, and instructions were identical across groups to minimize measurement bias.

The chosen sample size (N = 28) was based on feasibility and comparability with prior experimental studies on DOMS recovery interventions, which typically include small-to-moderate cohorts ranging from 20 to 40 participants (Vaile et al., 2008; Jakeman et al 2009). While no a priori power calculation was conducted, the sample size was deemed adequate for exploratory analysis, with results interpreted cautiously considering this limitation.

Procedures

Induction of Delayed Onset Muscle Soreness (DOMS)

DOMS was experimentally induced through a standardized squat protocol designed to overload the quadriceps musculature eccentrically, consistent with methods used in previous studies (Proske & Morgan, 2001; Chen et al., 2007). Each participant completed four sets of bodyweight squats to the point of local muscular failure, defined as the onset of a strong burning sensation in the thighs. From this threshold, participants were instructed to perform an additional 30 repetitions, ensuring sufficient muscular stress to elicit soreness. Between sets, participants rested for 90 seconds. This protocol reliably induced DOMS in the quadriceps and occasionally the hamstrings, resulting in reduced functional capacity of both the hip and knee.

Recovery Exercise Protocol (Exercise Group)

Participants randomized to the exercise group performed a structured daily program of light physical exercises during the recovery period, targeting major lower-limb muscle groups commonly affected by DOMS. The protocol consisted of:

1. Half-range squats (30 repetitions), primarily activating the quadriceps musculature.
2. Mini-bridges from supine position with knees flexed and feet grounded (30 repetitions), emphasizing hamstrings and gluteal activation.
3. Standing calf raises (50 repetitions), engaging the gastrocnemius–soleus complex.

This exercise protocol was selected because it provided low-intensity, closed-chain movements shown to promote circulation and neuromuscular activation without imposing excessive mechanical strain (Tufano et al 2017; Vaile et al 2008). The control group refrained from physical exercise during recovery but completed the same daily functional assessments as the exercise group.

Functional Mobility Assessment

To evaluate the functional impact of DOMS and track recovery, seated hip flexion with extended knees was selected as the reference movement. In this standardized test, participants sat on the floor with knees fully extended and attempted to bend forward to reach or surpass their toes. Hip flexion was chosen because hamstrings, glutes and also quadriceps soreness directly limits this action, making it a sensitive and practical functional indicator (Byrne et al., 2004).

Video Recording and Kinovea Calibration

All mobility tests were video-recorded and analyzed using Kinovea software (version 0.9.5), an open-source motion analysis program validated in sports biomechanics (Puig-Diví et al., 2019). To ensure consistent and accurate measurements, a calibration procedure was performed for each recording:

- A reference scale of 100 calibration points was placed along the longitudinal axis of the foot, with the foot kept in a neutral position (toes pointing vertically).
- Using this calibrated scale, the distance between the participant’s fingertips and the tip of the foot was extracted as the mobility outcome.

- This calibration method eliminated potential errors due to perspective or anthropometric variability, ensuring comparability across participants.

Coding of Mobility Values

To facilitate standardized analysis across participants, raw values were converted into coded scores in 10° increments. A score of 0 represented baseline mobility, positive values reflected improvements beyond baseline, and negative values indicated regression. For example:

- 12.43 cm = 0 (baseline),
- 17.71 cm = –1 (regression),
- 29.95 cm = –3 (greater regression),
- 3.30 cm = +1 (improvement).

This approach provided an ordinal scale suitable for tracking mobility changes over time, while simplifying inter-individual comparisons (similar scoring approaches have been used in other DOMS and recovery studies; Connolly et al., 2003).

Daily Follow-Up

A baseline test was conducted prior to the induction protocol. Following the squat protocol, participants repeated the mobility test every morning for five consecutive days, with each session recorded and analyzed as described above. DOMS typically appeared within 24–48 hours and resolved fully by Day 5 in all participants, consistent with established timelines reported in the literature (Cheung et al., 2003; Howatson & van Someren, 2008).

Handling of Missing Data

As DOMS duration varied (2–5 days across individuals), participants who recovered earlier did not exhibit mobility restrictions on subsequent days. To allow repeated-measures analysis, all missing post-recovery values were coded as 0 (baseline mobility), representing full functional restoration. This approach ensured equal observation points per participant while conservatively estimating recovery trajectories.

Measures

Primary Outcome

The primary outcome of the study was the number of days until DOMS resolution, operationally defined as the disappearance of muscle soreness and the restoration of baseline hip flexion mobility. This functional endpoint was chosen because it reflects both the subjective recovery from discomfort and the objective return of mobility, which are critical for athletes and physically active individuals (Cheung et al., 2003; Byrne, Twist, & Eston, 2004).

Secondary Outcomes

Secondary outcomes included **daily hip flexion mobility scores**, coded according to the procedure described above. These values allowed the trajectory of recovery to be analyzed day by day, rather than relying solely on the endpoint of full symptom resolution. Such longitudinal tracking provides greater sensitivity to subtle changes in mobility and is consistent with best practices in monitoring exercise-induced muscle damage (Howatson & van Someren, 2008; Twist & Eston, 2009).

The dual approach—endpoint analysis (time to recovery) and repeated-measures analysis (daily coded mobility)—enabled the study to address both clinical relevance and detailed recovery dynamics.

Statistical Analysis

Data were analyzed in SPSS 27. Descriptive statistics were computed for each group. Between-group differences in recovery time were tested with an independent-samples t-test. To assess changes in mobility across days and groups, a mixed ANOVA was conducted with Day (five levels) as a within-subject factor and Group (exercise vs. control) as a between-subject factor. Mauchly's test of sphericity was used to verify the assumption of sphericity, and when violated, Greenhouse–Geisser corrections were applied (Girden, 1992). Statistical significance was set at $p < .05$, as recommended in exercise physiology research (Atkinson & Nevill, 1998).

RESULTS

Primary Outcome: Days to Recovery

The mean number of days until DOMS resolution was 31.89 (SD = 15.12) in the exercise group and 30.66 (SD = 19.69) in the control group. An independent-samples t-test revealed no significant difference between groups, $t(26) = 0.19$, $p = .855$, 95% CI [−12.41, 14.87]. These results suggest that engaging in light physical exercise did not significantly accelerate recovery compared with inactivity.

Secondary Outcomes: Daily Mobility Trajectories

A mixed-design ANOVA with Day (1–5) as the within-subjects factor and Group (exercise vs. control) as the between-subjects factor indicated:

- A main effect of Day, $F(5,130) = 2.06$, $p = .074$, $\eta^2p = .073$, which did not reach statistical significance after Greenhouse-Geisser correction ($p = .124$).
- No significant Day × Group interaction, $F(5,130) = 0.48$, $p = .789$, $\eta^2p = .018$.
- No significant main effect of Group, $F(1,26) = 0.14$, $p = .710$, $\eta^2p = .005$.

These results indicate that mobility improved progressively across days in both groups, but the pattern of recovery did not differ significantly between exercise and control participants.

Exploratory Independent-Samples t-Tests by Day

Independent-samples t-tests were conducted for each day of follow-up (Days 1–5). Results showed no significant differences between groups at any time point:

- **Day 1:** *t(26) = 0.75, p = .463, 95% CI [−2.01, 4.30]*
- ***Day 2:*** *t(19.72) = 0.63, p = .536, 95% CI [−1.49, 2.77]*
- ***Day 3:*** *t(26) = −0.26, p = .795, 95% CI [−2.52, 1.95]*
- ***Day 4:*** *t(26) = −0.54, p = .596, 95% CI [−1.72, 1.01]*
- ***Day 5:*** $t(26) = 0.22$, $p = .824$, 95% CI [−1.23, 1.52]

All confidence intervals included zero, and effect sizes were negligible (Cohen's $d < 0.30$).

Summary

Taken together, both the primary endpoint and secondary analyses indicated that light exercise performed during the recovery period from DOMS did not significantly influence the time course of recovery or daily mobility outcomes compared with inactivity.

DISCUSSION

The present randomized controlled trial investigated whether engaging in light physical exercise during delayed onset muscle soreness (DOMS) would accelerate recovery compared with inactivity. Contrary to the initial hypothesis, both the primary endpoint (days to recovery) and secondary analyses (daily mobility trajectories) revealed no significant group differences. Participants in both exercise and control groups experienced progressive improvement in mobility, with soreness subsiding by Day 5, consistent with the well-established natural time course of DOMS (Cheung et al., 2003; Howatson & van Someren, 2008).

Interpretation of Findings

Our findings align with studies that have reported no significant advantage of active recovery over passive rest in alleviating DOMS (Isabell et al., 1992; Jakeman et al 2009). Although light exercise has been hypothesized to increase blood flow and facilitate metabolite clearance, the lack of observed differences suggests that these mechanisms may not be sufficient to alter the underlying inflammatory and structural processes driving DOMS (Proske & Morgan, 2001; Armstrong, 1990). It is possible that while exercise may temporarily modulate soreness perception, it does not meaningfully influence the overall duration of recovery, as indicated by our results.

Conversely, other investigations have reported benefits of active recovery strategies, including reduced soreness and improved performance (Zainuddin et al., 2006; Vaile et al., 2008). Differences between those studies and the present trial may be attributable to variations in exercise modality, intensity, and timing of interventions, as well as the use of different outcome measures (e.g., pain ratings vs. functional mobility). Our use of a functional mobility test rather than subjective pain scales may have provided a more objective assessment but may also capture different aspects of recovery.

Strengths and Limitations

A key strength of this study is the use of video analysis with Kinovea software, calibrated to foot length, which allowed precise and reproducible measurement of hip flexion mobility. In addition, the coding system reduced anthropometric variability and enabled standardized comparisons across participants.

However, several limitations should be acknowledged. First, the sample size was modest (N = 28), which may have limited statistical power to detect small effects. Second, the intervention consisted of unspecific light exercise rather than a carefully standardized recovery protocol, potentially reducing sensitivity. Third, the study focused exclusively on functional mobility, without incorporating subjective pain ratings or biochemical markers of muscle damage, which may have provided a more comprehensive picture of recovery. Finally, the relatively young and healthy participant group limits the generalizability of findings to other populations such as elite athletes or older adults.

Practical Implications

From a practical perspective, the findings suggest that light physical exercise during DOMS neither accelerates nor delays recovery when compared with rest. This indicates that athletes and recreational exercisers may safely choose either strategy depending on personal preference, comfort, and training schedules, without concern for significantly prolonging recovery.

Future Directions

Future studies should aim to replicate these findings with larger sample sizes, more standardized active recovery protocols (e.g., low-intensity cycling or resistance exercise), and multimodal outcome measures, including both subjective soreness ratings and objective performance indicators. Additionally, integrating biomarkers of inflammation and muscle damage could help clarify the physiological mechanisms underpinning recovery dynamics.

CONCLUSIONS

This randomized controlled trial investigated whether light physical exercise could accelerate recovery from delayed onset muscle soreness (DOMS) compared with inactivity. The results demonstrated no significant differences between groups in either recovery time or daily mobility trajectories. Both exercise and control participants experienced progressive improvement, with full resolution of DOMS by Day 5.

These findings suggest that light exercise during DOMS neither accelerates nor impairs recovery relative to rest. While the study employed objective functional measures and standardized assessments, limitations related to sample size and intervention specificity warrant cautious interpretation. Future research with larger cohorts, multimodal outcome measures, and carefully standardized exercise interventions is recommended to further clarify the role of active recovery in managing DOMS.

AUTHOR CONTRIBUTIONS

The author solely conceived and designed the study, developed the methodology, conducted data collection, performed the statistical analyses, interpreted the results, and wrote and revised the manuscript. The author has read and approved the final version of the manuscript and agrees to be accountable for all aspects of the work.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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MEN'S 100-METER FREESTYLE: A TEMPORAL AND BIOMECHANICAL ANALYSIS

Marcel RĂSĂDEAN [1*], Bianca BĂLAȘ[1], Dan Ionuț PÎRJOL[1]

ABSTRACT. The men's 100-meter freestyle event represents a benchmark discipline in competitive swimming, marked by biomechanical complexity, intense physiological demands, and distinctive strategic dynamics. With a longstanding tradition in international competitions, this event requires an optimal combination of speed, power, technique, and recovery capacity. The main objective of this research was to analyze the biomechanical and temporal parameters of the world's top swimmers in the 100-meter freestyle, in order to identify execution patterns that can contribute to optimizing performance. The study involved a comparative analysis of twelve elite athletes, examining indicators such as split times across the two 50-meter segments, number of stroke cycles, and stroke amplitude. Data were collected from official international competition sources and interpreted through the lens of applied biomechanics. Findings revealed that the highest-performing athletes exhibit minimal temporal and biomechanical amplitude differences between race segments. Pan Zhanle set a new world record (46.40 s), characterized by a well-balanced start and consistent speed maintenance. The analysis of stroke count highlighted the swimmers' ability to sustain technical stability despite increased metabolic load. The research confirms the hypothesis that top performance in the 100-meter freestyle is decisively influenced by biomechanical balance and strategic effort distribution. Effective strategies are associated with minimal variation in stroke frequency and split times—critical factors in achieving elite-level results. This study provides a relevant analytical framework for coaches and high-performance swimmers, contributing to the development of evidence-based training methodologies in competitive swimming.

Keywords: competitive swimming, elite athletes, 100-meter freestyle, comparative analysis

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INTRODUCTION

Over the years, the 100-meter freestyle event has become a barometer of excellence in competitive swimming. Performances have evolved remarkably, due to advances in training methods as well as innovations in equipment and pool design. The 100-meter freestyle, one of the most spectacular and competitive disciplines in high-performance swimming, has been exemplified by the outstanding progression of Romanian swimmer David Popovici, a true phenomenon of world swimming. Popovici has drawn the attention of the international community through a rare combination of talent, discipline, strategy, and technical innovation. His outstanding achievements—including world titles, European and World records, and remarkable consistency at a young age—served as the inspiration and motivation for choosing this topic. What distinguishes David Popovici is not merely his record-setting achievements, but the way he has redefined the technical and strategic understanding of the 100-meter freestyle, emphasizing efficiency and fluidity over sheer power and explosiveness.

Hypothesis

The outstanding performance of Chinese swimmer Pan Zhanle in the 100-meter freestyle at the 2024 Paris Olympic Games stands out through the breaking of his own previous world record.

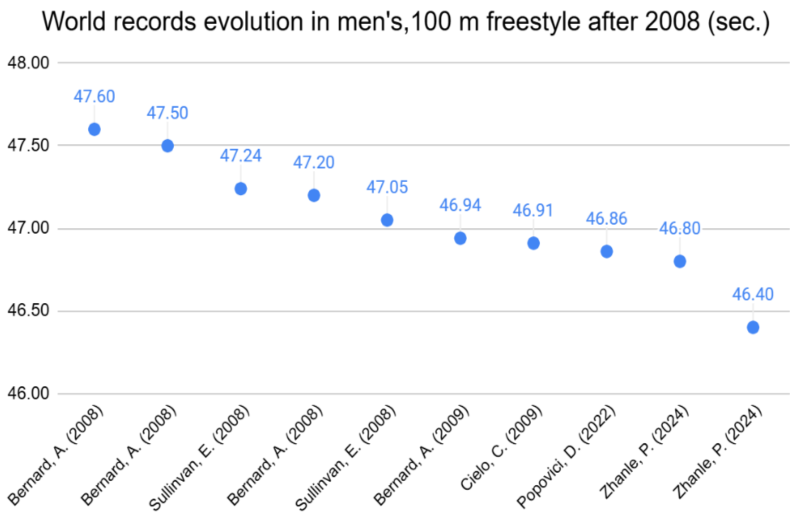

Fig. 1. Progression of world records in men's 100 m freestyle since 2008

The new world record of 46.40 seconds marks a significant improvement of 0.40 seconds compared to the previous record of 46.80 seconds—a notable difference considering the historical progression of records in this event.

This progression is particularly remarkable given that previous improvements at this level of performance were limited to mere hundredths of a second, as illustrated by the results of other elite swimmers such as David Popovici (46.86) and Cesar Cielo (46.91). Thus, Pan Zhanle's qualitative leap opens a pertinent debate about the human limits of performance in this event and the potential to break the new record in the near future.

The present study is based on the hypothesis that, through an analysis of the times recorded by the highest-performing swimmers in the 100-meter freestyle event, it is possible to identify structural similarities in race execution strategies. More specifically, the research examines the distribution of swimming velocity across the two race segments (the first and second pool lengths) with the aim of identifying common performance patterns or strategic differentiators in execution.

MATERIAL AND METHODS

For the purpose of this study, the races performed by the most accomplished athletes in the men's 100-meter freestyle event were analyzed in order to identify common elements related to race strategy and speed distribution.

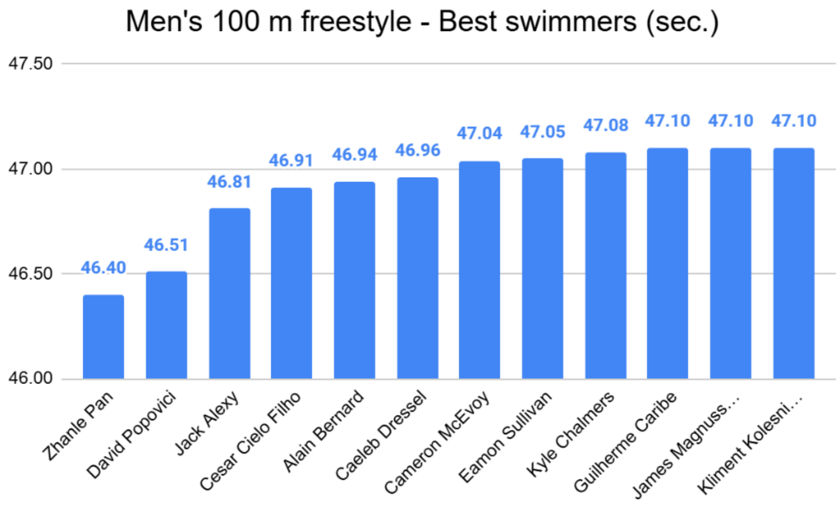

Fig. 2. Top 12 personal best male swimmers in the 100 m freestyle event

According to official World Aquatics rankings, the top 12 swimmers are: Pan Zhanle (China), David Popovici (Romania), Cesar Cielo Filho (Brazil), Alain Bernard (France), Caeleb Dressel (USA), Jack Alexy (USA), Cameron McEvoy (Australia), Eamon Sullivan (Australia), Kyle Chalmers (Australia), Guilherme Caribe (Brazil), James Magnussen (Australia), and Kliment Kolesnikov (Russia).

These athletes were selected based on top performances in major international competitions, representing benchmarks of excellence in contemporary world swimming.

In this study, the performances of the top 12 male swimmers in the 100-meter freestyle were analyzed with the aim of highlighting specific characteristics of race execution and identifying potential consistencies among elite athletes.

The evaluation was conducted based on the following indicators:

· Split time for the first 50 meters; split time for the second 50 meters; temporal amplitude;

· Number of arm strokes in the first segment of the race; number of arm strokes in the second segment; stroke frequency amplitude.

The data were centralized and subjected to comparative analysis to identify strategic patterns that could explain elite-level performance.

RESULTS

Analysis of split times in the first half of the race reveals clear tendencies regarding start strategy and effort distribution. Split times for the first 50 meters ranged between 22.17 seconds (Cesar Cielo Filho) and 22.79 seconds (Kyle Chalmers), with an average of 22.44 seconds. Swimmers such as Cesar Cielo Filho (22.17 s) and Pan Zhanle (22.28 s) demonstrate an aggressive race approach, characterized by an initial burst of speed typical of athletes with pronounced anaerobic qualities and exceptional acceleration capacity. This strategy aims to gain an early advantage and maintain control of the race from a leading position.

A second group of swimmers, including David Popovici (22.49 s) and Jack Alexy (22.45 s), prefer a more conservative race approach, marked by a slightly lower speed during the first half of the event, conserving energy for the second segment. In contrast, athletes such as Kyle Chalmers (22.79 s) and James Magnussen (22.68 s) adopt a slower start in the initial part of the race. This choice may indicate an energy-conservation strategy designed to sustain a more consistent pace throughout the event. It may also reflect a superiority of the aerobic system, allowing for a gradual increase in intensity without a significant decline in efficiency toward the end of the race.

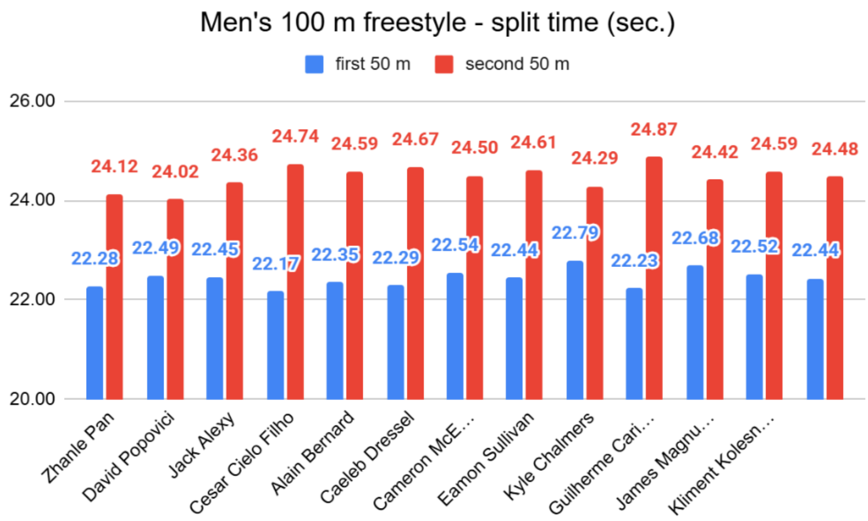

Fig. 3. Split times in the men's 100 m freestyle event

The second segment (last 50 meters) is critical for final success, reflecting the swimmer's ability to sustain speed under lactate pressure and energy depletion. In this segment, the recorded times show greater variation, ranging from 24.02 seconds (David Popovici) to 24.87 seconds (Guilherme Caribe), with an average of 24.48 seconds. It is remarkable that David Popovici not only registers the fastest time on the second length but even a faster split than some athletes achieved on the first segment, confirming his reputation as a specialist in the *negative split* (a second half faster than the first). Zhanle Pan also falls within the optimal performance range (24.12 s), indicating an ability to maintain a pace close to his initial rhythm even after an explosive first segment.

Conversely, athletes such as Cesar Cielo Filho (24.74 s), Caeleb Dressel (24.67 s), and Alain Bernard (24.59 s) record significant decreases in speed, suggesting either a sharp metabolic decline or an excessively demanding anaerobic effort during the first part of the race.

This distribution of times in the second segment highlights clear physiological and biomechanical differences among the athletes: those with an endurance-oriented profile (e.g., Popovici) are capable of sustaining a strong finish, whereas pure sprinters tend to experience a considerable drop in performance due to insufficient oxidative capacity.

The temporal amplitude, calculated as the difference between the time of the second segment and that of the first segment of the race, provides an integrative view of rhythmic balance in race execution. This value varies significantly, ranging from 1.50 seconds (Kyle Chalmers) to 2.57 seconds (Cesar Cielo Filho), highlighting major strategic and physiological differences among athletes.

A reduced amplitude reflects a high level of consistency and metabolic efficiency, allowing for an almost equal distribution of effort between the two segments of the race. This model is considered ideal from both a physiological and biomechanical standpoint and serves as a reference for modern sprint-endurance–oriented training methodologies.

At the opposite end, Cielo Filho (2.57 s) and Dressel (2.38 s) exhibit a pronounced decrease in speed during the second half of the race. This decline can be attributed to the rapid depletion of phosphocreatine reserves and the accumulation of lactate, as well as to a swimming style excessively focused on power rather than energy conservation.

Despite registering a moderate amplitude (1.84 s), Zhanle Pan manages to maintain a relatively constant speed despite an explosive start. This indicates a mixed physiological profile, combining strong anaerobic capacity with superior biomechanical efficiency.

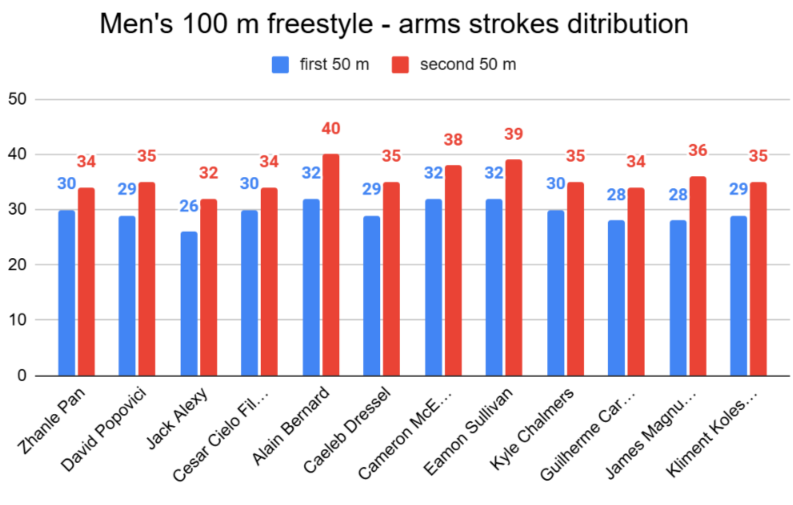

Fig. 4. Men’s 100 m freestyle – arm strokes distribution

The number of arm strokes performed during the first segment of the race represents a key biomechanical indicator for assessing an athlete’s technical efficiency in the acceleration phase. On average, the swimmers analyzed recorded between 26 and 32 strokes, with the lowest value observed for Jack Alexy (26) and the highest for Alain Bernard (32), yielding an average of 29.58 strokes.

A lower stroke count in this portion of the race generally suggests efficient glide and greater stroke amplitude, reflecting well-calibrated biomechanics conducive to energy economy. Conversely, a higher stroke count may be interpreted in two ways: either as a result of an intentionally aggressive strategy with increased stroke frequency, or as an indication of reduced stroke amplitude, which requires additional effort to maintain speed.

In the second segment of the race, the number of arm strokes increases significantly for all swimmers, ranging from 33 (Jack Alexy) to 40 (Alain Bernard), with an average of 35.58 strokes. This increase is physiologically and biomechanically natural, as in the final part of the race, swimmers compensate for decreased strength and amplitude by increasing frequency to sustain velocity.

Swimmers such as Alain Bernard (40 strokes) exhibit a marked increase in frequency, which may indicate a substantial reduction in propulsive efficiency due to fatigue. In contrast, athletes such as Pan Zhanle (34) and Cesar Cielo Filho (34) maintain a high frequency within a balanced biomechanical range, demonstrating superior technical control.

It is noteworthy that at this stage of the race, stroke frequency control becomes a critical factor: an excessive increase can lead to technical imbalances, while a frequency that is too low cannot compensate for the loss of muscular power. The difference between the number of strokes executed in the second segment compared with the first reflects the degree of biomechanical adaptation to fatigue and can serve as an indicator of an athlete's overall technico-physiological efficiency.

The smallest differences were recorded by Pan Zhanle and Cesar Cielo Filho (+4 strokes), indicating a remarkable ability to maintain biomechanical consistency even under maximal effort. This level of stability is characteristic of high-performance athletes with strong physical conditioning and refined technical preparation.

Conversely, larger amplitudes—such as those observed in Alain Bernard and James Magnussen (+8 strokes)—may signal either a deterioration in technical efficiency during the final seconds of the race or a deliberate strategy to increase frequency as a compensatory response to muscular fatigue and reduced stroke amplitude. The greater the difference in stroke count, the higher the athlete's susceptibility to biomechanical control loss and postural imbalances, which may negatively affect forward velocity and overall race efficiency.

DISCUSSION

The results obtained in this study confirm the working hypothesis and align with the main objective formulated — namely, to identify execution patterns in the men's 100-meter freestyle event through a comparative analysis of swimming speed distribution and stroke frequency across race segments.

The remarkable performance of Pan Zhanle, culminating in the establishment of a new world record (00:46.40), is supported by a balanced biomechanical and temporal profile, reflected in the reduced amplitude of both split times and stroke frequency between the two race segments. Specifically, a temporal amplitude of 1.84 seconds and a +4 stroke difference between segments indicate a controlled, efficient, and reproducible race strategy at an elite level.

A comparison of these findings with existing literature further reinforces the conclusions. The study conducted by Emel Cetin et al. (2017) demonstrated that experienced swimmers manage to maintain a consistent stroke length, compensating only minimally for reductions in propulsive amplitude. Similarly, López-Plaza et al. (2024) showed that the stability of *stroke rate* and *stroke length* throughout the race—known as *stroke steadiness*—is a determining factor for high performance in sprint events. Both studies support the premise that minimal biomechanical and energetic variations are positively correlated with competitive results.

Furthermore, recent research by Morais et al. (2022, 2023) confirmed that low biomechanical amplitude and consistent race strategies are common characteristics among elite athletes in international competitions.

Nevertheless, the present study also has certain limitations. Firstly, the sample selection focused exclusively on top-level athletes (the 12 best swimmers worldwide), which restricts the generalizability of the conclusions to mid-level or amateur populations. Secondly, the absence of a full analysis of physiological variables (e.g., oxygen consumption, lactate concentration, heart rate) limits the depth of understanding regarding the metabolic mechanisms underlying effort distribution. In addition, the lack of direct integration of video analysis reduces the precision of dynamic assessments of stroke technique.

On the other hand, by correlating biomechanical data (stroke count), temporal data (split times), and final results (total time), this study provides an interpretive model applicable to performance evaluation in competitive contexts. It also offers a valuable reference framework for the planning of elite-level training programs.

For future research, it is recommended to expand the sample by including both male and female athletes, as well as younger age categories, to outline a model of progressive performance development. Moreover, the integration of 3D video analysis technologies and physiological parameters could provide deeper insights into the relationship between biomechanics, race strategy, and final performance outcomes.

CONCLUSIONS

The results obtained from the analysis of temporal and biomechanical parameters in the men's 100-meter freestyle event clearly support the study's hypothesis—that elite swimmers' top performances can be understood and differentiated by examining how they structure their races, particularly in terms of speed distribution and stroke dynamics across the two race segments.

The exceptional performance of Chinese swimmer Pan Zhanle, marked by setting a new world record of 00:46.40 seconds at the Paris 2024 Olympic Games, is validated and explained in light of the biomechanical and temporal data. This time represents a significant improvement over his previous record of 00:46.80, constituting a 0.40-second enhancement. Considering that the progression of world records in this event has typically occurred in minimal increments, his achievement exceeds the standard evolutionary trend observed in this discipline.

Compared with other elite athletes such as David Popovici and Cesar Cielo Filho, Pan Zhanle demonstrates a balanced distribution of effort across both pool lengths. His time in the first segment (22.28 seconds) ranks among the faster splits, though not excessively so, while his second-segment time (24.12 seconds) is one of the most stable, indicating high efficiency in maintaining speed under metabolic fatigue. This equilibrium is reflected in a moderate temporal amplitude (1.84 seconds), signaling a coherent strategy that balances the initial impulse with controlled effort during the final phase of the race.

Regarding stroke count analysis, the data reveal a general tendency for increased frequency in the second half of the race. However, the variations between segments are crucial for biomechanical profiling. Pan Zhanle and Cesar Cielo Filho both recorded a +4 stroke amplitude, suggesting an ability to sustain a stable and efficient technique until the race's end. In contrast, swimmers such as Alain Bernard and James Magnussen showed increases of up to +8 strokes, reflecting a pronounced decline in technical efficiency, likely caused by accumulated fatigue and reduced propulsive amplitude.

Therefore, the integration of temporal and biomechanical analysis confirms the existence of distinct strategic patterns in race execution. A high-performance profile can be characterized by reduced amplitudes both in temporal and biomechanical dimensions, indicating optimal adaptation to race demands. The execution model demonstrated by Pan Zhanle—based on a controlled start, consistent return phase, and balanced biomechanical frequency—emerges as one of the most efficient approaches in elite swimming.

In this respect, the study's hypothesis is supported not only empirically but also functionally, providing a valuable explanatory framework for understanding the mechanisms underlying elite performance and opening new perspectives for optimizing race strategies, particularly in anticipation of future major competitions.

AUTHOR CONTRIBUTIONS

All contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there are no financial or personal conflicts of interest that have influenced this study.

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THE IMPACT OF PROFESSIONAL ACTIVITY NURSES HEALTH – RISK FACTORS AND PREVENTION STRATEGIES THROUGH PHYSICAL ACTIVITY AND SUPPORT PROGRAMS

Virgil Romulus RUS[1*], Horea ȘTEFĂNESCU[2]

ABSTRACT. ***Introduction***: The professional activity of nurses is associated with high physical and psychological demands, which may lead to musculoskeletal disorders and a decrease in professional quality of life. Nursing is recognized for its nobility and importance, but also for the significant physical and mental strain it entails. ***Objectives***: This study investigates the impact of professional activity on the physical health of nurses, with a focus on the body regions most affected and the symptoms reported, comparing results by sex and age groups. Additionally, it aims to explore the main body areas experiencing discomfort after a workday among nurses. ***Methods***: An observational questionnaire-based study was conducted on a sample of 12 active nurses. Data were analyzed using descriptive and comparative statistics and are presented in tables and graphs. ***Results***: The most frequently reported problems were lumbar and cervical pain. Significant differences were observed between sexes and age categories. Overall, 91.7% of participants reported discomfort in one or more body regions, with the cervical region and spine being the most affected. Additional symptoms included water retention, headaches, mental fatigue, and stress. ***Conclusions:*** Professional activity has a major impact on the physical health of nurses. The implementation of occupational health and safety (OHS) and psychological measures, along with further studies on larger samples, may be beneficial. Ergonomic programs and organizational prevention policies are strongly recommended.

Keywords: nurses; musculoskeletal disorders; occupational health; ergonomics; burnout

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INTRODUCTION

The nursing profession plays a central role in healthcare systems worldwide, combining a high level of social responsibility with intense physical and psychological demands. Beyond their essential contribution to patient care, nurses are exposed daily to occupational risks that can have a significant impact on their health and quality of life.

Among these risks, work-related musculoskeletal disorders (WMSDs) stand out as one of the most prevalent health problems. International research consistently shows that the lumbar spine, cervical region, and shoulders are the most frequently affected areas, reflecting the specific demands of nursing practice, such as patient lifting and mobilization, prolonged static postures, and repetitive manual tasks. While global data confirm the endemic nature of WMSDs among nurses, evidence from Romania remains scarce. The lack of detailed national statistics highlights a critical gap in the literature, even though the professional context mirrors international trends: repetitive physical effort, fast-paced work environments, and insufficient ergonomic prevention strategies.

Furthermore, the impact of these disorders extends beyond physical health. Numerous studies indicate strong associations between WMSDs, occupational stress, burnout, and reduced quality of life, underlining the complex nature of the challenges faced by nurses.

Table 1. Comparative analysis: Romania and other Eastern European countries

Country	Work schedule	Documented conditions	Social impact	Recommended measures
Romania	40h/week, max. 48h; frequent shifts	Moderate-to-high burnout (~75%), frequent lumbar pain	Fatigue, absenteeism, staff turnover	Multicomponent programs (exercise + ergonomics + psychological support)
Bulgaria	40h/week; long shifts in large hospitals	Frequent musculoskeletal complaints	Retention difficulties, intermittent absenteeism	Patient handling training, participatory ergonomics
Hungary	40h/week, up to 12h/day legally	High stress, sleep disturbances	Fatigue and risk of errors	Shift optimization, light exposure, micro-exercise interventions
Poland	8h/day, 40h/week average	Burnout in ICU and psychiatry	Reduced patient satisfaction	Multicomponent ergonomics, physical activity programs
Czechia/Slovakia	40h/week, ≤12h shifts	High burnout, comparable WMSD rates	Errors associated with fatigue	Sleep-friendly rotation, occupational health policies
Serbia	40h/week; extended shifts	High prevalence of lumbar pain	Impact on continuity of care	Transfer equipment, trunk/shoulder exercise programs

These considerations emphasize the urgent need for applied research aimed at documenting the prevalence and severity of WMSDs in Romania or in other countries (Table 1 Comparative analysis: Romania and other Eastern European countries) and supporting the development of interventions tailored to the local context. Addressing this gap is crucial not only for improving occupational health strategies but also for safeguarding the wellbeing and sustainability of a profession vital to healthcare delivery.

General objective

The general objective of this research is to analyze the impact of professional activity on the physical health of nurses by identifying and characterizing work-related musculoskeletal symptoms, their severity, and the contextual factors that may influence them. In a context where the prevalence of musculoskeletal disorders among healthcare personnel exceeds 75% worldwide (Sun et al., 2023), this study aims to provide data adapted to the Romanian hospital environment, contributing to international literature and supporting the development of ergonomic and organizational interventions. From this general aim, the following specific objectives are derived:

- Determining the prevalence of musculoskeletal discomfort among nurses – quantifying the proportion of medical staff experiencing discomfort in different body regions. Identifying the most affected areas (e.g., lumbar spine, cervical region, lower limbs) helps define priority intervention domains (Martin et al., 2025).
- Assessing the severity of reported symptoms – measuring symptom severity levels, from mild to severe. Pain intensity directly influences work capacity, professional quality of life, and absenteeism risk. Identifying severity categories not only confirms prevalence but also highlights the urgency of interventions (Jacquier-Bret & Gorce, 2025).
- Analyzing differences by sex and age – examining significant differences between sexes and age groups in symptom prevalence and severity. This analysis enables the design of personalized prevention programs (Yue et al., 2021).
- Identifying associated non-musculoskeletal symptoms – highlighting related manifestations such as mental fatigue, stress, headaches, or water retention. Although less prevalent, these symptoms reflect the complex interplay between physical and psychological health (Zhang et al., 2022).
- Correlating symptoms with occupational risk factors – exploring the relationship between symptoms and determinants such as prolonged static postures, long shifts, manual patient lifting, and lack of ergonomic equipment. This objective supports the identification of causal links and justifies organizational-level interventions (Özkan et al., 2023).

Developing these objectives contributes to a deeper understanding of the impact of work on nurses' physical health. They allow not only the quantification of the problem but also the formulation of practical recommendations tailored to the real needs of healthcare staff. By integrating musculoskeletal and psychological symptoms, the study proposes a holistic approach to occupational health (Table 2 Occupational Health Assessment Tools in Nurses), consistent with current trends in international research.

Table 2. Occupational Health Assessment Tools in Nurses

Acronym / Full Name	Evaluated field	Structure / Scoring	Use in medical personnel
PSQI – Pittsburgh Sleep Quality Index	Sleep quality (latency, duration, efficiency, diurnal dysfunctions)	19 items, overall score 0–21 (score >5 = poor sleep)	Evaluation of the effects of shifts on sleep; monitoring of interventions (napping, light, physical exercise)
FSS – Fatigue Severity Scale	Severity of fatigue and impact on daily functioning	9 items, Likert scale 1–7; mean score >4 = severe fatigue	Measurement of chronic fatigue in shift staff, ICU, UPU
MBI – Maslach Burnout Inventory	Level of burnout (emotional exhaustion, depersonalization, personal fulfillment)	22 items, three subscales; higher scores indicate increased level of burnout	Identifying the level of burnout in nurses and doctors
NMQ – Nordic Musculoskeletal Questionnaire	Prevalence and localization of musculoskeletal pain	Questions by anatomical regions, reporting symptoms in the last 12 months / 7 days	Monitoring the prevalence of WMSD (low back, neck, shoulder pain)
GHQ – General Health Questionnaire	General psychological health (anxiety, depression, stress)	12–28 items, overall score; higher scores indicate mental impairment	Screening for general mental health in an occupational context

MATERIAL AND METHODS

Study design

This research employed a descriptive observational design to evaluate the impact of professional activity on the physical health of nurses, allowing prevalence and severity to be analyzed in a naturalistic setting without external interventions (Polit & Beck, 2021). The observational study was conducted on a sample of 12 active nurses from various wards. It included questions about affected areas, symptom types, their frequency, and impact on professional activity. The study is descriptive and transparent with respect to data collection and reporting.

Population and sample

Participants were active nurses employed in public and private hospitals. Inclusion criteria were age 22–60 years, at least one year of professional activity, and absence of severe neurological diagnoses. A convenience sample of 12 respondents was recruited (70% women; 30% men), reflecting the typical gender structure of the profession in Romania (Eurofound, 2022).

Instruments and variables

Data were collected via a structured questionnaire adapted from the Nordic Musculoskeletal Questionnaire (Kuorinka et al., 1987). Sections included: demographics (age, sex, tenure), affected body regions, symptom intensity (Likert 1–5), and associated symptoms (fatigue, stress, headaches). Content validity was verified by two occupational health experts.

Data collection procedure

Questionnaires were distributed electronically; completion was voluntary and anonymous. Participants provided informed consent after being briefed on objectives. The response rate was 92% (Creswell & Creswell, 2021).

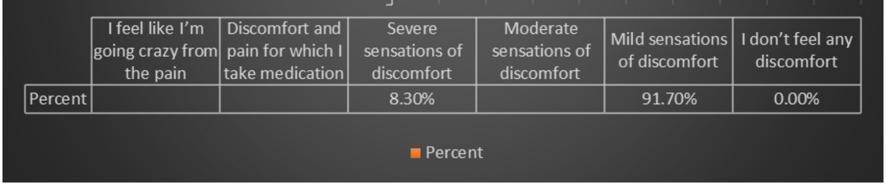
Statistical analysis

Data were processed using descriptive statistics (percentages and means). Results are presented in tables and figures.

Ethical considerations

The study complied with the Declaration of Helsinki (2013). Informed consent was obtained; data were anonymized; and no conflicts of interest were declared.

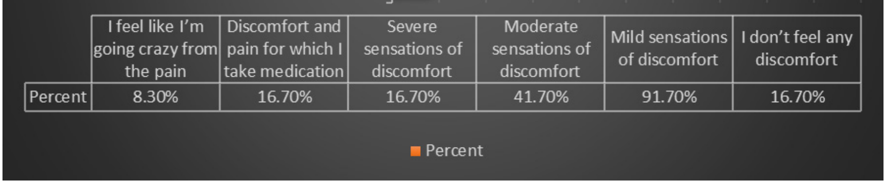
a. A day's work the sensations that the research subjects feel after a day of work “0. I don’t feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I’m going crazy from the pain;” (Figure 1).



	I feel like I'm going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don't feel any discomfort
Percent			8.30%		91.70%	0.00%

Fig. 1. The sensations that the research subjects feel after a day of work

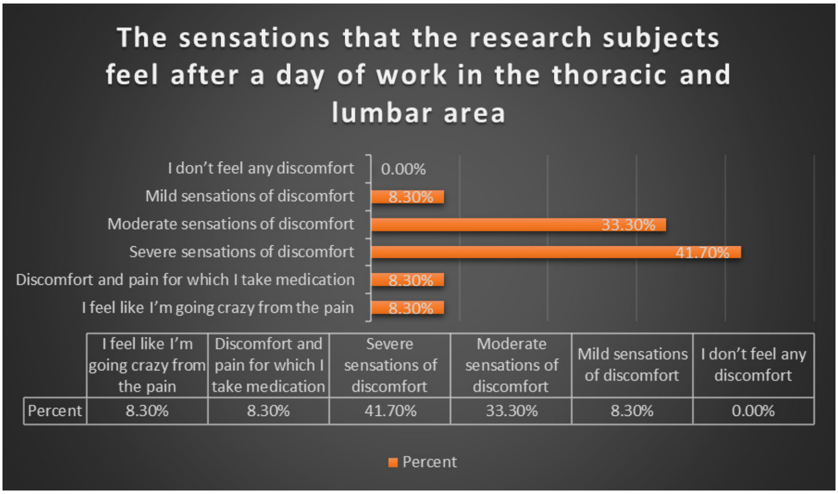
b. Head-neck – cervical area the sensations that the research subjects feel after a day's work in the cervical area "0. I don't feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I'm going crazy from the pain;" (Figure 2)



	I feel like I'm going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don't feel any discomfort
Percent	8.30%	16.70%	16.70%	41.70%	91.70%	16.70%

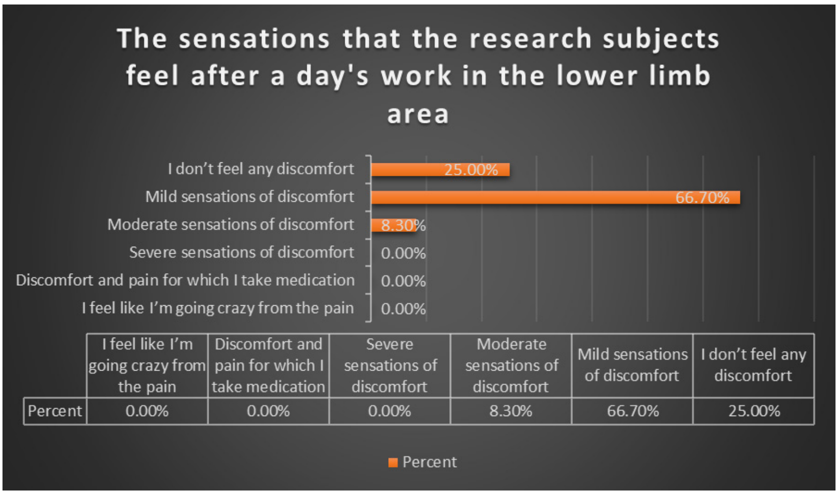
Fig. 2. The sensations that the research subjects feel after a day's work in the cervical area

c. Torso, spine, thoracic and lumbar area, the sensations that the research subjects feel after a day of work in the thoracic and lumbar area "0. I don't feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I'm going crazy from the pain;" (Figure 3)



	I feel like I'm going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don't feel any discomfort
Percent	8.30%	8.30%	41.70%	33.30%	8.30%	0.00%

Fig. 3. The sensations that the research subjects feel after a day of work in the thoracic and lumbar area

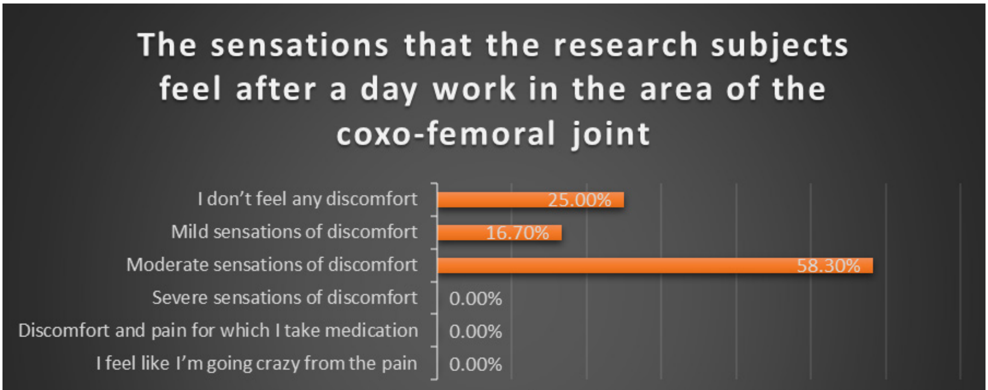


	I feel like I'm going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don't feel any discomfort
Percent	0.00%	0.00%	0.00%	8.30%	66.70%	25.00%

Fig. 4. Sensations that research subjects experience after a day's work in the lower limb area

d. Upper body, shoulders, elbows, wrists, sensations that research subjects experience after a day's work in the lower limb area “0. I don’t feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I’m going crazy from the pain;” (Figure 4)

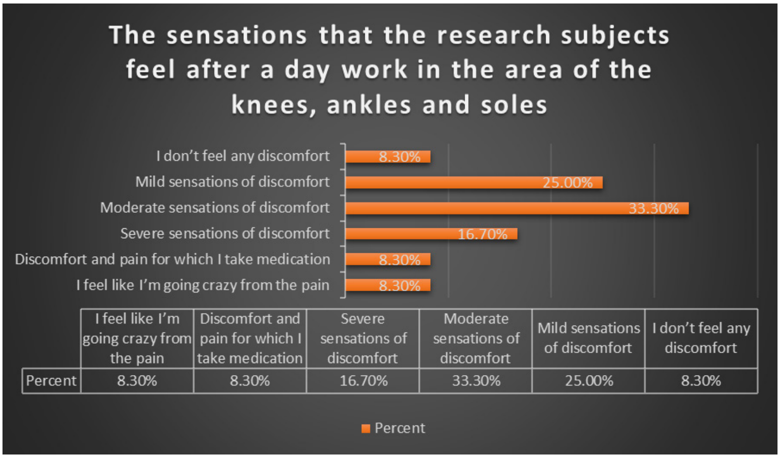
e. Pelvis, coxofemoral joint, hips, the sensations that the research subjects feel after a day of work in the area of the coxo-femoral joint, “0. I don’t feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I’m going crazy from the pain;” (Figure 5)



	I feel like I’m going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don’t feel any discomfort
Percent	0.00%	0.00%	0.00%	58.30%	16.70%	25.00%

Fig. 5. The sensations that the research subjects feel after a day of work in the area of the coxo-femoral joint

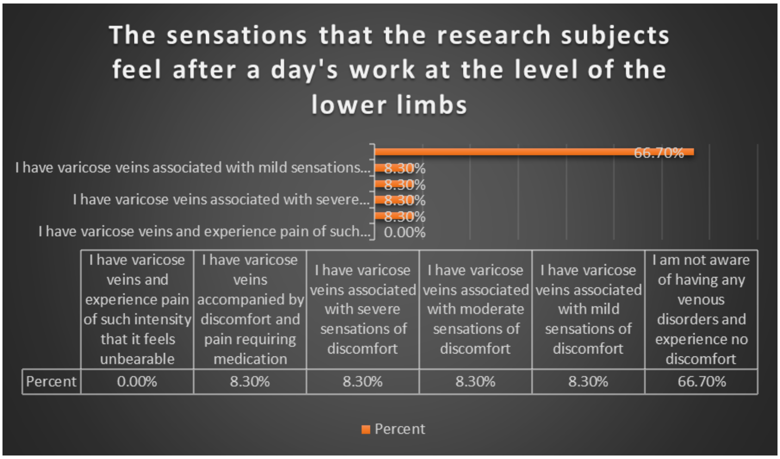
f. Lower body, knee joints, ankles, soles the sensations that the research subjects feel after a day of work in the area of the knees, ankles and soles” 0. I don’t feel any discomfort; 1. Mild sensations of discomfort; 2. Moderate sensations of discomfort; 3. Severe sensations of discomfort; 4. Discomfort and pain for which I take medication; 5. I feel like I’m going crazy from the pain;” (Figure 6)



	I feel like I'm going crazy from the pain	Discomfort and pain for which I take medication	Severe sensations of discomfort	Moderate sensations of discomfort	Mild sensations of discomfort	I don't feel any discomfort
Percent	8.30%	8.30%	16.70%	33.30%	25.00%	8.30%

Fig. 6. The sensations that the research subjects feel after a day of work in the area of the knees, ankles and soles

g. Other sensation of discomfort the sensations that the research subjects feel after a day's work at the level of the lower limbs "0. I am not aware of having any venous disorders and experience no discomfort; 1. I have varicose veins associated with mild sensations of discomfort; 2. I have varicose veins associated with moderate sensations of discomfort; 3. I have varicose veins associated with severe sensations of discomfort; 4. I have varicose veins accompanied by discomfort and pain requiring medication; 5. I have varicose veins and experience pain of such intensity that it feels unbearable;" (Figure 7)



	I have varicose veins and experience pain of such intensity that it feels unbearable	I have varicose veins accompanied by discomfort and pain requiring medication	I have varicose veins associated with severe sensations of discomfort	I have varicose veins associated with moderate sensations of discomfort	I have varicose veins associated with mild sensations of discomfort	I am not aware of having any venous disorders and experience no discomfort
Percent	0.00%	8.30%	8.30%	8.30%	8.30%	66.70%

Fig. 7. The sensations that the research subjects feel after a day's work at the level of the lower limbs

Data analysis

The data were statistically processed by frequencies and percentages (Table 3 Distribution of musculoskeletal symptoms), and the results were presented in comparative tables and graphs.

Table 3. Distribution of musculoskeletal symptoms

Symptom / Affected area	Prevalence (%)	Reported level	Further comments
General discomfort (body segment)	91.7	—	Very high prevalence
Cervical area	83.3	Moderate – extreme	Tension, muscle pain
Backbone	58.3	Major – Extreme	Stiffness, chronic pain
Lower limbs	64.3	Medium – extreme	Cramps, fatigue
Water retention	8.3	Mild – moderate	Associated symptom
Headaches	8.3	Mild – moderate	Associated symptom
Mental fatigue	8.3	Mild – moderate	Stress-related
Stress	8.3	Mild – moderate	Correlated with mental fatigue

RESULTS

The study revealed a high prevalence of musculoskeletal symptoms among the participating nurses. Overall, 91.7% reported discomfort in one or more body segments. The most affected regions were the cervical area (83.3%), spinal column (58.3%), and lower limbs (64.3%). Additional symptoms—water retention, headaches, psychological fatigue, and stress—were each reported by 8.3% of participants. Comparative analyses indicated that women more frequently reported lumbar and cervical pain, whereas men more often reported pain in the upper and lower limbs (Table 4 Comparing symptoms by gender). Differences were statistically significant for the cervical region ($p < .05$). Age-stratified analyses suggested lower chronic pain incidence among younger staff (22–35 years), with symptom intensity increasing with age and years of service.

Table 4. Comparing symptoms by gender

Affected area	Women (%)	Men (%)
Lumbar region	50	35
Cervical region	35	20
Lower limbs	10	20
Upper limbs	5	15

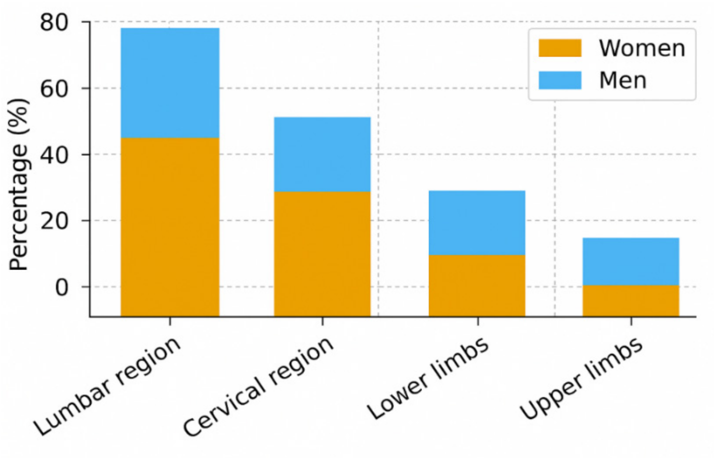


Fig. 8. Different for each important body region

The conceptual model (Figure 8) highlights the causal chain between risk factors, symptoms and consequences on professional performance. The limitations of the study include the small number of participants and its local nature, which limits the generalization of the conclusions.

Analysis highlighting gender differences in the occupational health of nurses

Studies reveal specific patterns in the prevalence of musculoskeletal disorders, burnout, sleep disturbances, and social impact, which justify differentiated measures of prevention and support. (Figure 9).

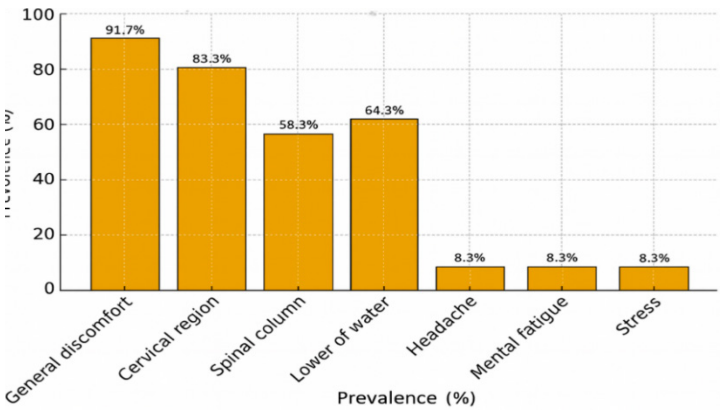


Fig. 9. Prevalence of symptoms

In order to gain a clearer understanding of the causal mechanisms, we present below a conceptual model of the interaction of risk factors, symptomatic manifestations and their effects. “Incorrect physical exertion à risk factors à static postures à lifting patients à low back pain à neck pain, limb pain, decreased performance” (Figure 10).

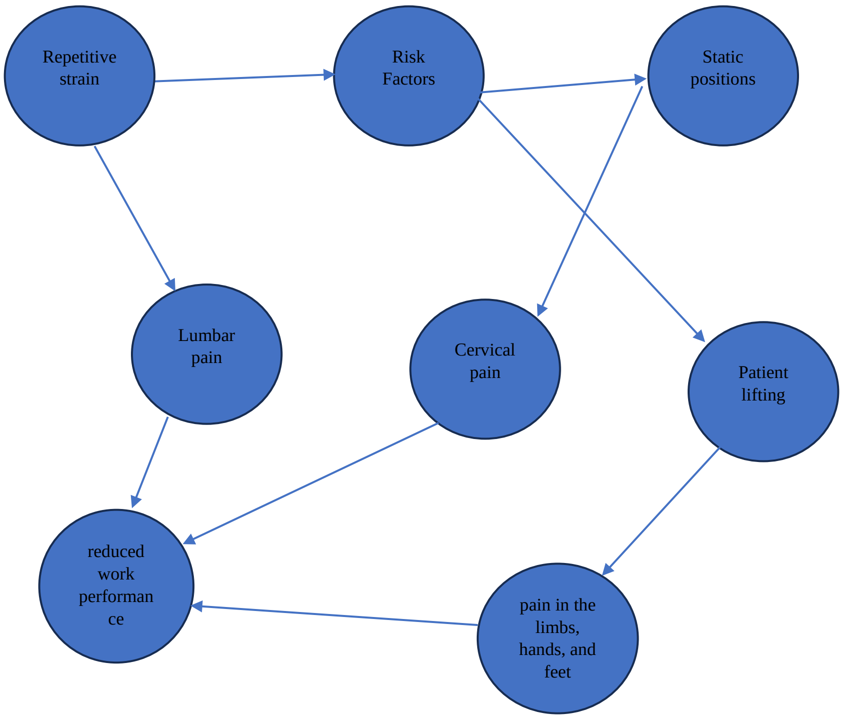


Fig. 10. The link between risk factors, symptoms and consequences

DISCUSSIONS

The results obtained confirm the high prevalence of musculoskeletal disorders among nurses, in accordance with the international literature. Recent meta-analyses report an overall prevalence of 77–80% (Sun et al., 2023; Martin et al., 2025), and the data from this study indicate even higher values (91.7%), suggesting that Romanian nurses are at significant risk. The differences observed between sexes and age groups are similar to the results of other research (Yue et al., 2021), suggesting that physiological factors and characteristics of occupational tasks influence the distribution of symptoms (Table 5 Current practices versus proposed recommendations for the prevention of musculoskeletal pain).

An important aspect is the associated symptoms, such as stress and mental fatigue. They reflect the link between physical and mental health, confirmed by recent studies that have highlighted correlations between chronic pain and burnout in healthcare professionals (Zhang et al., 2022). Thus, the prevention of musculoskeletal disorders must be integrated into a holistic strategy, which includes both ergonomic measures and psychological support. Likely causes include prolonged postures, lifting patients, lack of breaks, and physical overload. The results confirm the prevalence of low back and neck pain in nurses, in accordance with the international literature (Trinkoff et al., 2007). The comparative analysis shows that women report lower back and neck pain more frequently, while men report limb pain more frequently. These differences can be explained by the distribution of tasks in the workplace and physiological differences. The reported psychiatric symptoms indicate the existence of an interdependence between occupational stress and somatic manifestations (Caruso, 2018).

Table 5. Current practices versus proposed recommendations for the prevention of musculoskeletal pain

Current practices	Proposed recommendations
Manual patient pick-up	Use of mechanical equipment and ergonomic techniques
Rare breaks during shifts	Introducing stretching breaks and short exercises, even "gym class" in the hospital's fitness room
Lack of periodic training	Regulars trainigs of SSM
Focus on productivity	Focus on employee health and prevention
Specific seminars (rarely)	Increase the number of specialized seminars that include practical applications*

CONCLUSIONS

The study showed a very high prevalence of musculoskeletal symptoms among nurses, especially in the cervical area, spine and lower limbs. These results confirm the importance of implementing prevention programs and adapted organizational policies.

General recommendations include:

- introduction of periodic ergonomics training;
- the use of mechanical equipment for lifting patients;
- organizing active breaks with stretching exercises;

- occupational health monitoring programs;
- integration of psychological support services to reduce stress and mental fatigue.

Future research directions should include longitudinal, multicenter studies and evaluations of the effectiveness of ergonomic interventions in reducing the prevalence of musculoskeletal disorders in healthcare professionals. The professional activity of nurses has a major impact on physical health, especially on the lumbar and cervical regions. The results underline the importance of implementing OSH and prevention programmes. Recommendations include appropriate equipment, safety and security training, regular breaks, and organizational support programs. The vast majority of nurses suffer from daily physical discomfort. The most affected areas are the neck and spine. It is necessary to implement prevention programs, even gyms inside hospitals where nurses can take active breaks under the supervision of the coach specialized in compensatory and relaxation physical exercises, seminars with appropriate topics by inviting specialists in the field of sports and with topics related to body posture and ergonomic-functional movements, and also psychological support where appropriate. Future studies with larger samples are essential to understand the extent of the problem.

Longitudinal and multicenter studies are needed to investigate the impact of ergonomic interventions on the musculoskeletal health of nurses. Future research should also include the correlation between physical health and phenomena such as occupational stress and burnout.

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EFFECTS OF SWIMMING ON THE MORPHOFUNCTIONAL DEVELOPMENT OF YOUNG ADULTS AGED 20 TO 30 YEARS

Adriana SLUSAR[1], Elena VIZITIU LAKHDARI[2*]

ABSTRACT. Swimming is considered one of the most complex physical activities due to the involvement of multiple muscle groups and the support it provides for cardiovascular health. Regular practice of swimming represents an effective means of improving the morpho functional capacity of young adults. Objective: The study aimed to investigate the effects of regular swimming on the development of morpho functional capacities in young adults aged between 20 and 30 years. It sought to determine the extent to which swimming contributes to the optimization of physical performance and health indicators. Materials and Methods: The study was conducted at the Swimming and Kinetotherapy Complex, where a group of participants within the specified age range was selected. They were monitored throughout a structured swimming program conducted over a period of twelve weeks. Initial and final assessments included measurements of body composition using the "Tanita" device, as well as functional capacity tests performed before and after the experimental program. Results: The results highlighted significant improvements in body composition, with a decrease in body fat percentage and an increase in lean muscle mass. Cardiovascular endurance also showed measurable progress. Discussion: The findings of this study are consistent with previous research emphasizing the beneficial effects of swimming on morpho functional development, confirming that regular practice generates both structural and functional adaptations. Conclusions: Swimming represents an effective strategy for improving morpho functional development in young adults aged between 20 and 30 years.

Keywords: effects, swimming, morpho functional development, young people

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INTRODUCTION

Swimming represents a complex form of physical activity that engages both the cardiovascular and muscular systems, exerting beneficial effects on the physical and psycho-emotional well-being of young adults. Studies show that regular swimming contributes to improved body composition, increased muscle mass, reduced body fat, posture correction, and the harmonious development of the body. Important parameters influencing these effects include the duration, frequency, and intensity of training, water temperature, and any dietary restrictions. Moreover, swimming promotes flexibility, muscle tone, and physical work capacity, while also having positive effects on mental health by reducing stress and anxiety. Few studies have analyzed the effects of swimming on the morpho functional development of young adults aged between 20 and 30 years. The study by (Răzvan et al., 2019) shows that sports contribute to the optimization of somatic parameters, such as blood circulation, heart rate, hormonal balance, and muscle tone, while also having positive effects on self-esteem and the perception of one's body image. Similarly, the study by (Grishko et al., 2021) demonstrates that students who engage in regular physical exercise maintain physical development indicators within normal limits and achieve a better psychological and motivational state for physical activity.

Another study (Mozolev et al., 2021) highlights the importance of maintaining adult women's health, especially during maturity, when motor activity decreases and stress increases, while (Vysotskaya et al., 2020) emphasize the importance of women's health for their social and productive functions. According to the authors (Dakal & Kachalov, 2024; Zhou et al., 2020), swimming represents a unique form of physical exercise, accessible to all ages and effective for overall health and physical development. Research conducted by (Zrnić et al., 2022) confirms that a sedentary lifestyle negatively affects health, while (Czajka & Sławińska, 2011) emphasize that somatic structure and physical condition undergo continuous changes throughout life, influenced by genetic and environmental factors. In this context, the (WHO, 2020) recommends limiting sedentary behavior and replacing it with physical activity of any intensity, including light activity, to prevent health problems. Research by (Cioroiu & Moldovan, 2009) shows that swimming not only maintains physical condition but also ensures harmonious development, relaxes muscle groups, and improves circulation and posture through the combination of static and dynamic exercises. Other research (Folsom et al., 1993) highlights that the waist-to-hip ratio is a better marker than body mass index for estimating the risk of mortality in older women, recommending its measurement in health monitoring. Additionally, studies by (Lampadari et al., 2015) emphasize that a sedentary lifestyle is part of the daily routine for most people, promoting the development of overweight and obesity, and that adults need regular physical activity to lose and maintain weight. Swimming or other water-based exercises are among the most popular forms of physical activity, providing benefits for both physical and mental health.

MATERIAL AND METHODS

Objective of the study: The study aimed to investigate the effects of regular swimming on the development of morpho functional capacities in young adults aged between 20 and 30 years, focusing on the extent to which this activity contributes to the optimization of physical performance and health indicators. Research methods: The methods used included analysis of the specialized literature, observation, experimental method, physical testing, mathematical-statistical analysis (mean, standard deviation, and coefficient of variation), and tabular-graphical representation of the data.

Participants

The study included 26 women aged between 20 and 30 years. Initial and final assessments were conducted using the Tanita device at the Swimming and Kinesiotherapy Complex. Prior to participation, all subjects provided informed consent and were clearly informed about the purpose of the study, the procedures applied, as well as potential risks and benefits. Participants were also assured that they could withdraw at any time without experiencing any negative consequences.

Procedure

Participants were selected according to the inclusion criteria: women aged between 20 and 30 years, without cardiovascular conditions or other health issues that could prevent participation in the swimming program, with consistent attendance at swimming lessons, and possessing basic swimming skills. The study, focused on the effects of swimming on morpho functional development, was conducted at the Swimming and Kinetotherapy Complex, where participants followed a structured swimming program over a period of 12 weeks. Before the start of the program, initial assessments were conducted, including body composition measurements (BMI, fat mass, muscle mass, bone mass, visceral fat, ECW, ICW, chronological age, and metabolic age) using the Tanita analyzer; Functional capacity tests (cardiovascular endurance, flexibility, and muscle strength). The swimming program was conducted three or four times per week, with sessions lasting 40–50 minutes, adapted to the stages and intensity of training. At the end of the 12 weeks, final assessments identical to the initial ones were performed to determine changes in body composition, functional capacity, and physical performance. All data were collected and analyzed in accordance with ethical principles and standard scientific methods.

Materials

The following materials and equipment were used for the study: Swimming pool located within the Swimming and Kinetotherapy Complex, measuring 25 m in length, with a depth of 1.35 m in the platform area (over approximately 8 m) and a maximum depth of 2.5 m in the rest of the pool. It provides optimal conditions for conducting swimming exercises and lessons aimed at developing physical endurance.

Tanita body composition analyzer, used to determine total body mass and body composition components.

The 12-week swimming program for the participants included in the study will be presented in tables 1-3.

Table 1. Stage 1 – Weeks 1–4: Adaptation and Technique

Day	Warm-up	Main Exercises	Breaks	Core Strength Exercises	Breaks	Relaxation and Stretching
Monday	100 m swimming in preferred style	4×50 m freestyle/breaststroke /backstroke	30 sec	2×12 push-ups, 2×12 knee raises in water	30 sec	100 m relaxation swim + 5 min stretching
Wednesday	100 m swimming in preferred style	4×25 m breathing exercises + 4×25 m freestyle/back kicks with kickboard	20–30 sec	2×12 pull-ups on pool edge	30 sec	100 m relaxation swim + 5 min stretching
Friday	100–150 m swimming in preferred style	6×25 m freestyle, low intensity, focus on correct technique	20 sec	2×12 jumps in water	30 sec	100 m relaxation swim + 5 min stretching

Table 2. Stage 2 – Weeks 5–8: Endurance and Toning

Day	Warm-up	Main Exercises	Breaks	Strength and Core Exercises	Breaks	Relaxation and Stretching
Monday	200 m swimming in preferred style	6×50 m freestyle, medium intensity	30 sec	3×15 push-ups, 3×15 knee raises	30 sec	100 m relaxation swim + 5–10 min stretching
Wednesday	200 m swimming in preferred style	4×50 m breaststroke/ backstroke, alternating speed	30 sec	3×15 pull-ups on the pool edge (“wave breaker”)	30 sec	100 m relaxation swim + 5–10 min stretching
Friday	200 m swimming in preferred style	4×25 m sprint freestyle kicks, breaststroke with kickboard	20 sec	2×12–15 balance and core exercises	30 sec	100 m relaxation swim + 5–10 min stretching
Saturday	150 m swimming in preferred style	4×50 m freestyle + 4×25 m breaststroke	30 sec	3×12 jumps and push-ups in water	30 sec	100 m relaxation swim + 5–10 min stretching

Table 3. Stage 3 – Weeks 9–12: Performance and Optimization

Day	Warm-up	Main Exercises	Breaks	Strength and Core Exercises	Breaks	Relaxation and Stretching
Monday	300 m swimming in preferred style	8×50 m freestyle, medium-high intensity	15–20 sec	3×15 push-ups, 3×15 pull-ups	20–30 sec	200 m relaxation swim + 10 min stretching
Wednesda y	200 m swimming in preferred style	6×25 m sprint freestyle/ breaststroke/ backstroke, alternating strokes	20 sec	3×15 abs/back + swimming equipment (kickboards, tubes, etc.)	20–30 sec	200 m relaxation swim + 10 min stretching
Friday	300 m swimming in preferred style	4×50 m kicks with board + 4×50 m moderate freestyle	20–30 sec	3×15 core and balance exercises	20–30 sec	200 m relaxation swim + 10 min stretching
Saturday	200 m swimming in preferred style	8×25 m sprint + 4×50 m moderate freestyle	15–20 sec	3×15 push-ups + pull-ups	20–30 sec	200 m relaxation swim + 10 min stretch

RESULTS

The analysis of data obtained from the initial and final assessments allowed the identification of changes in body composition, metabolic age, and physical performance resulting from participation in the swimming program. The results are presented graphically, including mean values, standard deviations, and coefficients of variation for each analyzed indicator.

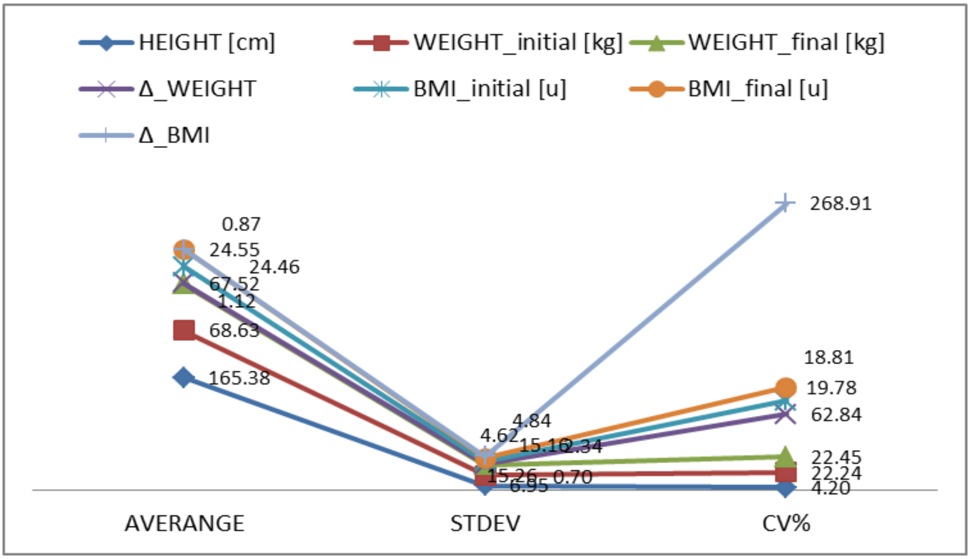

Fig. 1. Evolution of Participants' Weight and BMI

In (Figure 1), the average height of the participants can be observed, which is 165.38 cm, with a standard deviation of 6.95 cm, indicating a moderate variation among them. The coefficient of variation is 4.20%, suggesting that height is relatively homogeneous within the group. The initial weight shows a mean of 68.63 kg, while the final weight has a mean of 67.52 kg, indicating a decrease of 1.12 kg. The standard deviation for both initial and final weight is similar (approximately 15 kg), reflecting a high variability among participants. The coefficient of variation for weight is over 22%, suggesting that weight values are relatively dispersed within the group. Regarding the change in weight (Δ_Weight), it has a standard deviation of 0.70 kg and a CV% of 62.84%, indicating that weight loss or gain was very unevenly distributed among participants. For the Body Mass Index (BMI) test, the initial BMI has a mean of

24.46, while the final BMI has a mean of 24.55, resulting in an average increase of 0.87. The standard deviation for both initial and final BMI is approximately 4.6–4.8, indicating moderate variability among participants. The coefficient of variation for BMI is lower than for weight (approximately 19%), but for BMI variation (Δ_BMI), the CV% is very high at 268.91%, showing that changes in BMI were extremely uneven among participants.

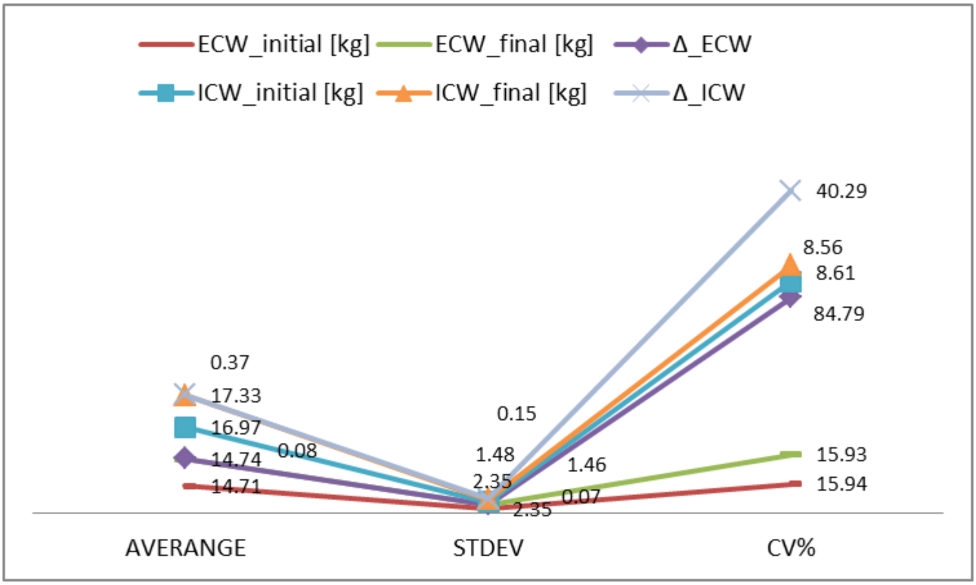

Fig. 2 Changes in Extracellular and Intracellular Body Water

In (Figure 2), the initial mean ECW is 14.71 kg, while the final mean ECW is 14.74 kg, indicating a very small average increase of 0.08 kg. The standard deviation is 2.35 kg for both initial and final ECW, reflecting moderate variability among participants. The coefficient of variation for ECW is approximately 16%, suggesting a moderate dispersion of values within the group. The ECW difference (D_ECW) has a very high CV% of 84.79%, indicating that individual changes were highly uneven: some participants experienced increases, others decreases, even though the mean change is nearly zero. Regarding ICW, the initial mean is 16.97 kg, and the final mean is 17.33 kg, resulting in an average increase of 0.37 kg.

The standard deviation for initial and final ICW is lower, at 1.46 kg-1.48 kg, showing less variability among participants compared to ECW. The CV% for initial and final ICW is approximately 8.6%, indicating greater uniformity of values. The ICW difference (D_ICW) has a CV% of 40.29%, showing that although the average increase is small, the variation between participants is quite significant.

In (Figure 3), the initial mean fat mass is 21.17 kg, while the final mean is 19.65 kg, indicating an average decrease of 1.52 kg. The standard deviation is relatively high, 9.78 kg initially and 9.27 kg finally, showing substantial variability among participants. The coefficient of variation for initial and final fat mass is high, 46–47%, confirming that fat mass values are widely dispersed among participants. The fat mass difference (Δ _Fat Mass) has a CV% of 60.75%, indicating that fat reduction was highly uneven among participants: some lost more fat, others less. Regarding muscle mass, the initial mean is 45.06 kg, and the final mean is 45.60 kg, resulting in an average increase of 0.54 kg. The standard deviation is lower, 5.76–5.81 kg compared to fat mass, indicating moderate variability among participants. The CV% for initial and final muscle mass is approximately 12–13%, suggesting greater uniformity of muscle mass among participants. The muscle mass change (Δ _Muscle Mass) has a high CV% of 71.89%, showing that although the average muscle gain is small, individual responses varied greatly among participants.

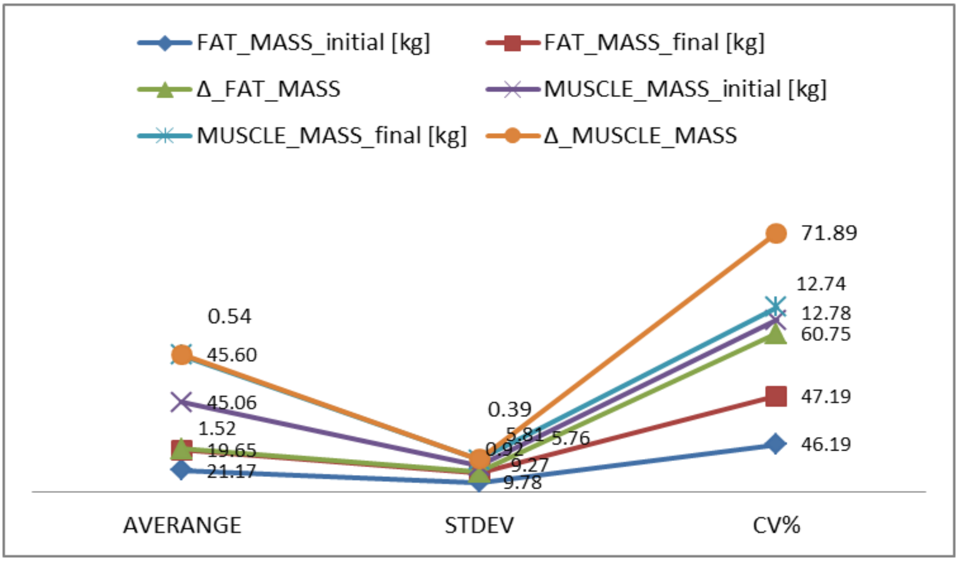

Fig. 3 Changes in Fat Mass and Muscle Mass

In (Figure 4), the mean initial and final bone mass is 2.41 kg, indicating an average change of 0 kg. The standard deviation is 0.29 kg, and the coefficient of variation is 12.07%, suggesting that bone mass values are relatively uniform among participants. Practically, bone mass did not undergo significant changes within the group, which is expected over a short period. Regarding visceral fat, the initial mean is 2.88, and the final mean is 2.08, resulting in an average decrease of 0.81 levels. The standard deviation for initial and final values is 2.10 and 1.44, respectively, and the CV% is very high at 72.67% and 69.25%, indicating a highly variable distribution among participants. The visceral fat change (Δ _Visceral Fat) has a CV% of 106.66%, showing that the reduction in visceral fat was extremely uneven among participants: some experienced large decreases, while others had smaller decreases or no change at all.

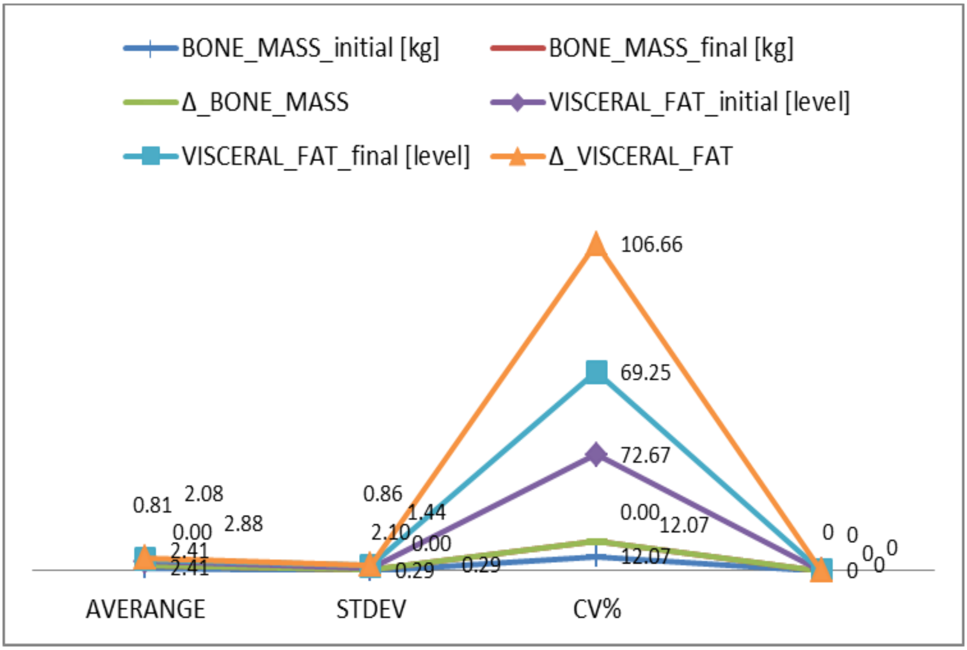

Fig. 4 Changes in Bone Mass and Visceral Fat

In Figure 5, the mean chronological age is 23.15 years, while the mean initial metabolic age is 25.27 years. This suggests that, at the beginning, the participants metabolism corresponded to that of a person approximately 2 years older than their actual age. This difference indicates a slightly slower metabolic rate or a suboptimal body composition, possibly due to higher fat mass or lower muscle mass. After the intervention, the mean metabolic age is 22.08 years, nearly 1 year younger than the chronological age. This indicates an improvement in metabolism, suggesting that the intervention (physical activity, nutrition, body composition) had a positive effect on overall health and metabolic efficiency. The average difference between initial and final metabolic age is 3.19 years, representing a significant reduction. Practically, the participants “rejuvenated” metabolically by more than 3 years on average, bringing their metabolism closer to or even below the level corresponding to their chronological age, even though some participants already had a metabolic age significantly lower than their chronological age.

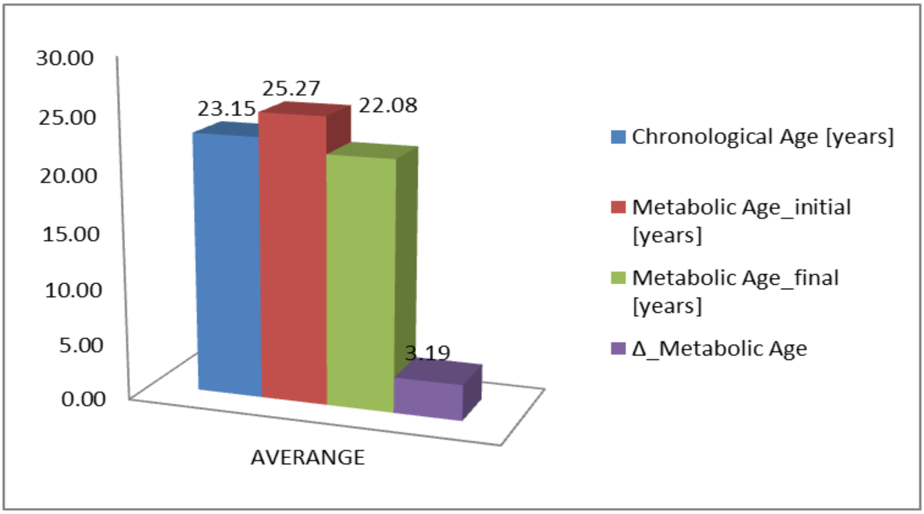

Fig. 5 Improvement of Metabolic Age in Relation to Chronological Age

In (Figure 6), the mean initial endurance is 154.23 m, while the final mean is 194.42 m, indicating an average increase of 40.19 m. The standard deviation for initial and final endurance is relatively small 9.78 m and 11.57 m, with a CV% of approximately 6%, showing that initial and final performances were relatively homogeneous among participants. The significant average increase indicates a clear improvement in swimming endurance. Regarding flexibility, the initial mean is 12.19 cm, and the final mean is 17.31 cm, resulting in an average increase of 5.12 cm. The standard deviation is small (approximately 1.5 cm) and CV% ranges between 8–13%, suggesting moderate variability among participants. The increase in flexibility demonstrates that the intervention had a positive effect on mobility and muscle stretching.

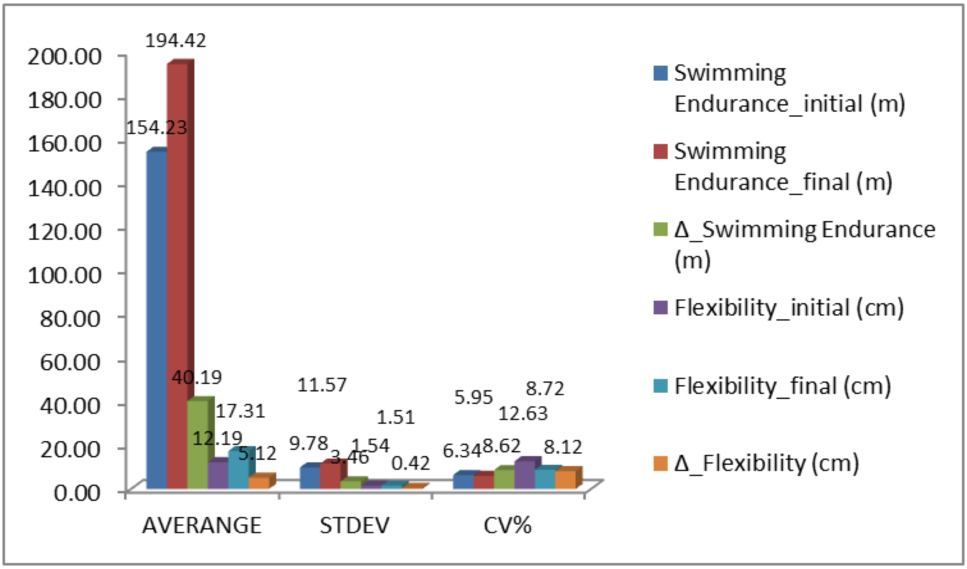

Fig. 6 Evolution of Physical Performance in Swimming and Flexibility

In (Figure 7), the mean initial strength is 18.31 repetitions, while the final mean is 24.81 repetitions, resulting in an average increase of 6.5 repetitions in 30 seconds. The standard deviation and CV% are relatively small, indicating that most participants experienced similar improvements in muscle strength.

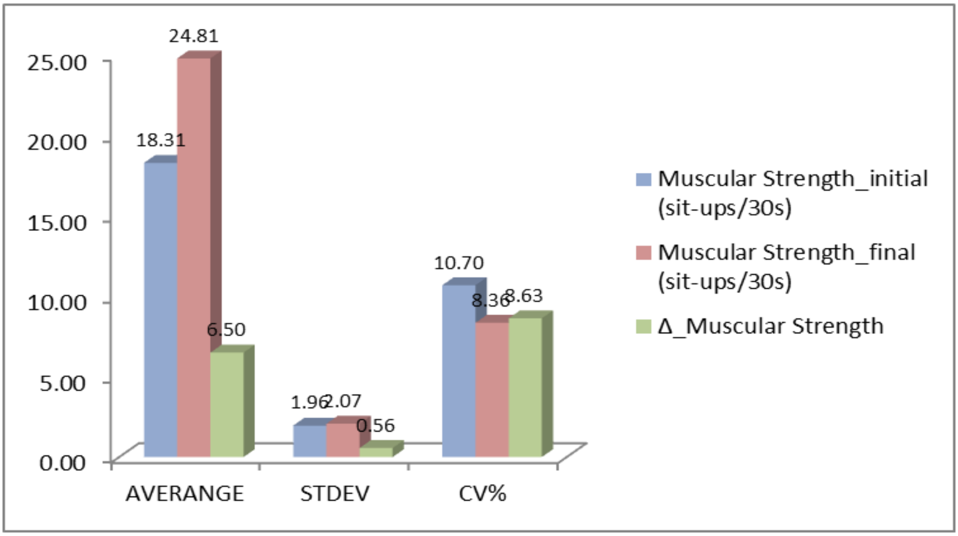

Fig. 7 Evolution of Participants' Abdominal Strength

DISCUSSION

The analyzed studies confirm the effectiveness of aquatic training on the physical and psycho-emotional condition of young adults. (Bondar et al., 2025) demonstrated that systematic swimming sessions improved work capacity (+4.9 units) and reduced stress levels (-3.4 points) in female students, without significantly affecting cardiovascular adaptive potential or body mass index. (Boltabayev et al., 2025) showed that swimming activities aimed at health promotion were more effective than running in improving physical fitness and work capacity in students (+2.9% vs. +2.4%). Another study by (Pirohova et al., 2021) highlighted the effectiveness of a differentiated approach in aqua fitness on women's body types, reducing class I and II obesity and increasing the proportion of those with normal weight (+13.37%). The authors (Rocha et al. 2007) confirmed that the Water Force program is effective in increasing the dynamics of maximal strength of the upper and lower limbs, showing significant differences between sexes ($p = 0.0360$). These results emphasize the benefits of aquatic training not only for improving physical performance but also for correcting body proportions and reducing stress, suggesting its applicability in various aquatic programs. The authors (Tuuri et al., 2002) found that swimming distance correlated with body fat (23%), waist circumference (26%), abdominal sagittal diameter (20%), and skinfolds (20–24%). Abdominal sagittal diameter was more strongly related to age ($R^2 = 0.29$) than swimming distance ($R^2 = 0.20$). Bone mineral content was negatively associated with age ($R^2 = 0.18$) and positively with swimming distance ($R^2 = 0.12$), while bone mineral density decreased with age ($R^2 = 0.12$).

CONCLUSIONS

The group showed small but positive changes in weight, BMI, ECW, and ICW, with significant individual variability, indicating that training responses differed among participants. Average reductions in fat mass and visceral fat were observed, along with slight increases in muscle mass, maintenance of bone mass, and a significant decrease in metabolic age, reflecting improvements in metabolic health and body composition. All assessed physical components swimming endurance, flexibility, and muscle strength improved significantly, with balanced progress, highlighting that swimming contributes to optimizing physical performance and functional capacity in young adults. Regular swimming proves to be a comprehensive activity that enhances both metabolic health and overall physical performance, supporting the balanced development of morpho functional capacities.

AUTHOR CONTRIBUTIONS

Slusar Adriana and Vizitiu Lakhdari Elena contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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BODY EXPRESSIVENESS, MOTOR SKILLS, AND ARTISTIC PRESENCE IN GYMNASTICS AND DANCE

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ABSTRACT. In artistic sports such as gymnastics and dance, body expressiveness functions as a powerful form of nonverbal communication and a decisive factor in performance quality. Motor skills—including coordination, strength, flexibility, and postural control—provide the technical foundation that allows athletes to convey musical themes, emotions, and complex artistic ideas with authenticity and precision. Musicality, understood as the ability to interpret, represent, and embody the music through movement, is equally essential: it transforms choreography into a vivid, emotionally engaging performance. Artistic presence, encompassing originality, fluid transitions, and emotional engagement, plays a critical role in modern scoring systems, where even minor differences in technical execution can be offset by superior artistry and expressive musical interpretation. Drawing from sports dance techniques and diverse choreographic approaches, coaches and athletes can access a wide range of movements, rhythms, and dynamic accents that amplify both the visual and emotional impact of a routine. By integrating musicality, body expressiveness, artistic presence, and motor development, athletes can elevate execution quality and enhance their potential for achieving top rankings in gymnastics and dance competitions.

Keywords: dance; gymnastics; artistic presence; body expressiveness; motor skills.

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INTRODUCTION

Body expressiveness and artistic presence have become central to contemporary performance in both dance and gymnastics. Artistic sports no longer rely exclusively on technical perfection but require athletes to communicate emotion and narrative through movement (Chappell et al., 2021). Dance, traditionally associated with aesthetic communication, provides an ideal framework for understanding how gestures, postures, and motor control support expressiveness (Dianhuai, 2023; Chirazi, 2022). Gymnastics, although rooted in athletic execution, has gradually integrated artistry as a decisive factor in evaluation, particularly in disciplines such as aerobic and rhythmic gymnastics (Ghezea, Stoica, Bota, Teodorescu, & Gherghel, 2025). Ballroom dancing is making an increasingly significant contribution to gymnastics choreography, particularly Latin American dances, which are more physically demanding than Standard dances (Liiv et. al., 2012), improves aerobic endurance and develops coordination, stimulating memory and body control (Van et. al., 2024).

Recent reviews show that dance and expressive movement contribute not only to aesthetic value but also to athletes' psychological well-being and social-emotional development (Narikbayeva et al., 2025), stimulating multiple intelligences (Tomescu, Bălan, Aivaz & Zahiu, 2025).

This article provides an integrative synthesis of research addressing the intersection of motor skill development, artistic expressiveness, and performance presence in gymnastics and dance.

BODY EXPRESSIVENESS AND NONVERBAL COMMUNICATION

Body expressiveness is a complex, nonverbal communication system where gestures, postures, and spatial dynamics transmit meaning beyond verbal language (Chirazi, 2022). It enables performers to translate emotions, intentions, and narratives into physical form, creating a silent yet powerful dialogue with the audience. In dance, this ability is foundational for conveying choreographic intention, allowing performers to interpret music and themes with authenticity and subtlety. This sport involves cognitive processes, motivations, attitudes, mental states, and various personality traits (Manos, 2016). Choreographers often rely on the dancer's capacity to embody abstract ideas, while spectators decode these physical signals through cultural and emotional lenses (Năstase, 2010).

In gymnastics, body expressiveness serves a different but equally crucial role: it transforms highly technical sequences into emotionally engaging performances. Without expressiveness, routines risk appearing mechanical and purely athletic. When athletes integrate fluid transitions, nuanced dynamics, and expressive gestures, their execution acquires depth and artistic identity. This expressive dimension has become increasingly relevant in disciplines such as aerobic and rhythmic gymnastics, where scoring systems reward not only technical precision but also presentation, interpretation, and creativity (Ghezea et al., 2025).

Moreover, Chappell et al. (2021) highlight that expressive movement enhances both aesthetic quality and psychological well-being across the lifespan. It fosters self-awareness, creativity, and emotional release, benefits that extend beyond the performance stage and support long-term athlete development (Bota, Urzeală & Mezei, 2012). Through body expressiveness, athletes bridge the gap between athletic skill and artistic storytelling, a quality audiences and judges alike perceive as artistry.

MOTOR SKILLS AND TECHNICAL FOUNDATIONS

Motor abilities such as coordination, balance, flexibility, and strength form the essential physical base that allows artistic elements to emerge authentically (Dianhuai, 2023). Psychomotor training and movement re-education shape the gymnasts' personality by linking action with the discovery of the environment for learning purposes (Tanasă et. al., 2024). Coordination enables athletes to execute complex movement sequences with timing and precision; balance ensures fluid control over posture and spatial orientation; flexibility expands the body's expressive range, while strength provides the dynamic power required for explosive jumps, sustained lines, and controlled landings. (Dianhuai, 2023)

Specialists in the field consider it necessary to educate the expressive aspects of motor skills. Dance allows the development of creativity, originality, sociability, and aesthetic posture through movement, contributing to the psychomotor development of athletes (Macovei, 2013). In gymnastics, postural control and dynamic strength are indispensable. Athletes must demonstrate stable support positions, explosive power in jumps, and precise rotations while maintaining composure and grace. Without a well-developed motor foundation, expressive movement risks instability or loss of control. Dancers, conversely, rely heavily on fine motor control to execute smooth transitions, intricate footwork, and expressive upper-body gestures. Fluidity and subtle emotional cues depend on muscular endurance and refined kinesthetic awareness.

Ghezea et al. (2025) underline that aerobic gymnastics increasingly rewards the seamless integration of technical mastery with creative, expressive movement. Judges evaluate not only the difficulty and accuracy of elements but also their artistic framing and musical coherence. This reflects a paradigm shift: physical preparation is no longer sufficient on its own but must serve as the platform for artistic innovation.

ARTISTIC PRESENCE AND EMOTIONAL ENGAGEMENT

Artistic presence refers to the performer's charisma, emotional projection, and ability to captivate the audience. It is a synthesis of confidence, authenticity, and energetic connection that transforms well-executed routines into memorable experiences. Stage presence involves more than smiling or posing; it requires internalizing the choreography's emotional tone and delivering it with conviction. As a creative process, dance involves the intellect for the correct representation of movements; emotions, as a natural form of expression; the body, as the external means of conveying the artistic form of dance; and personality, which animates the other components (Vișan, 2005).

Narikbayeva et al. (2025) report that dance-based training enhances social skills and emotional intelligence, which directly influence a performer's ability to connect with audiences and judges. Emotional intelligence supports the interpretation of music and narrative, enabling athletes to express vulnerability, strength, or joy through movement. Gymnasts who develop this expressive charisma often achieve superior scores, even when technical differences between competitors are minimal (Ghezea et al., 2025).

Artistic presence also contributes to psychological resilience. Performers who feel confident in their expressive identity cope better with competitive stress and engage audiences with authenticity. This element often distinguishes elite athletes, as technical mastery alone rarely guarantees long-term recognition without a compelling artistic voice (Manos, 2016).

INTERDISCIPLINARY SYNERGY: DANCE AND GYMNASTICS

Dance training enriches gymnastics by providing tools for musical interpretation, expressive transitions, and choreographic originality (Chappell et al., 2021). Ballet and contemporary dance, for instance, teach gymnasts fluidity, line extension, and dynamic phrasing, while modern dance fosters improvisation and personal expression. Such cross-training encourages gymnasts to approach routines not merely as a series of elements but as artistic compositions.

Conversely, gymnastic conditioning supports dancers' strength, power, and stability. Techniques such as plyometrics, core strengthening, and balance exercises from gymnastics help dancers achieve higher jumps, improved alignment, and injury prevention. This bidirectional exchange creates well-rounded performers capable of combining athletic power with expressive nuance (Macovei, 2013).

By integrating both fields, coaches can design training programs that cultivate physical excellence alongside creativity. This approach reflects contemporary judging trends in both gymnastics and dance, where versatility, innovation, and artistry increasingly define competitive success.

DISCUSSIONS

Reviewing the available literature reveals a strong consensus: performance quality in artistic sports emerges from the synergy of physical capability and expressive artistry. Dance research demonstrates the psychosocial and aesthetic benefits of movement creativity, highlighting its impact on confidence, social integration, and emotional well-being (Chappell et al., 2021; Dianhuai, 2023). Gymnastics literature (Ghezea et al., 2025) confirms the growing weight of artistry in scoring systems, emphasizing the necessity of combining physical training with expressive coaching.

Narikbayeva et al. (2025) further illustrate that creative dance fosters emotional intelligence, empathy, and social adaptability—skills that empower athletes to perform with authenticity under competitive pressure. Together, these findings suggest that traditional training models focused solely on strength and precision should evolve toward holistic methods that integrate psychological and artistic development.

CONCLUSIONS

This review highlights that motor skills, body expressiveness, and artistic presence form an inseparable triad in modern gymnastics and dance. Athletic excellence emerges not only from physical conditioning but also from the ability to communicate meaning and emotion through movement. We consider that coaches and educators should integrate dance-based techniques into gymnastics training to cultivate expressiveness, musicality, and emotional projection while maintaining technical rigor. Such interdisciplinary approaches can help athletes achieve competitive success and foster a richer, more meaningful experience for performers and audiences alike.

AUTHOR CONTRIBUTIONS

Spînu A., Ene-Voiculescu C. and Tomescu G. contributed to the design of the research and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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THE PREVALENCE OF BULLYING AMONG PRIMARY SCHOOL STUDENTS

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ABSTRACT. ***Introduction:*** Bullying is a widespread phenomenon among school populations, including in Romania. ***Objective:*** We aimed to determine the prevalence of bullying among primary school students, with a focus on the distribution of roles (victim, aggressor, victim-aggressor, uninvolved) and possible gender differences. ***Material and Methods****:* The study employed a cross-sectional design. The research sample consisted of 352 fourth-grade students from 7 schools. Data were collected by one of the researchers during physical education classes, using the Adolescent Peer Relations Instrument Bully/Target. The Adolescent Peer Relations Instrument Bully/Target is composed of 36 items that assess the two dimensions of bullying (perpetration and victimization) through a 6-point Likert scale, where 1 = never, 2 = sometimes, 3 = once or twice a month, 4 = once a week, 5 = several times a week, and 6 = daily. Statistical analyses were performed using IBM SPSS Statistics 20. ***Results****:* The findings showed that 48.3% of students were not involved in bullying, 28.7% were victims, 6.5% were aggressors, and 16.5% were victim-aggressors. The prevalence of bullying by gender was comparable. ***Conclusions****:* The study highlighted the magnitude of bullying from primary school age, as well as the need for early prevention programs. Interventions should adopt an integrative perspective, addressing all roles involved in the bullying cycle.

Keywords: bullying perpetration; victimization; primary school; prevalence; gender differences.

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INTRODUCTION

Bullying is a type of aggressive behavior that is perpetuated, or has a high likelihood of being perpetuated, by one or more individuals and is distinguished by a power imbalance, with the objective of causing physical, psychological, social, and/or educational harm (Gladden et al., 2014). Other authors state that there are three defining characteristics of the bullying phenomenon: the power imbalance, intention, and repetition (Olweus, 2010).

The phenomenon of bullying is widespread among the school population, including in Romania (UNESCO, 2019). Compared to the international literature, research of the bullying in Romanian schools is still at an early stage, particularly at the primary level.

The National Institute of Public Health conducted a nationwide study on a sample of 4,612 students regarding the prevalence of victimization at the national level and across different geographical regions. The research findings, published in the National Public Health Report on Children and Youth in Romania (2016), reveal that the incidence of victimization at the national level is 17.9%. With regard to the prevalence of victimization by geographical area, Transylvania records the highest percentage in the country, namely 25%, followed by Moldova with 18%, Banat with 17.4%, and Muntenia with 13.8%.

Cosma et al. (2015) conducted a study with a nationally representative sample of 4,882 students aged 10 to 16 and report that the prevalence of bullying perpetration is 30.8% among boys and 20.6% among girls. With regard to the prevalence of victimization, the authors report an incidence of 19.8% for boys and 13.9% for girls.

Bullying is also a widespread phenomenon within physical education classes (Jiménez-Barbero et al., 2020; Wei & Graber, 2023).

In Canada, Hurley and Mandigo (2010) found that in a sample of 234 adolescents, 11.1% were victims of physical bullying, 13.6% were victims of verbal bullying, and 12.8% were victims of social bullying.

Gano-Overway (2013) conducted a study in the United States with a sample of 528 students aged between 10 and 15. The author reports that 15% of the students are perpetrators, while 28% are victims.

Bullying has a negative impact both during schooling and in adulthood, manifested in difficulties with concentration, lower academic performance, absenteeism, depression, suicidal thoughts, drug use, and risky or illegal behaviors (Copeland et al., 2013; Gardella et al., 2016; Huang et al., 2018; Ttofi et al., 2016; Turner et al., 2013; Wolke et al., 2013).

All of these issues cast doubt on the education and health of schoolchildren, future adults, and society as a whole. Therefore, investigating the phenomenon of bullying becomes an urgent necessity, and taking into account scientific research, professional experiences, and the principle of prevention, we consider the final year of primary school to be a suitable choice for research.

Therefore, the present study aims to identify the prevalence of the bullying phenomenon among primary school students, with a focus on the distribution of roles (uninvolved, victim, perpetrator, bully-victim), as well as possible gender differences.

MATERIAL AND METHODS

This study was conducted using a descriptive, cross-sectional design. A quantitative method was employed in order to achieve the research objective. More specifically, a questionnaire assessing bullying and victimization among primary school students was used.

Participants

The research sample consisted of 352 students (174 boys and 178 girls) enrolled in the fourth grade during the 2024-2025 school year, coming from 7 schools.

The research was conducted in accordance with the Declaration of Helsinki for all participants. The study protocol received approval from the Research Ethics Committee of „Alexandru Ioan Cuza" University of Iași, Faculty of Physical Education and Sport.

Procedure

Following the review of the literature, an assessment instrument appropriate to the participants' age was selected for evaluating the two dimensions of bullying (perpetration and victimization). The questionnaire was administered by one of the study's researchers during physical education classes, between November 11, 2024, and December 17,2024.

Materials

To explore the prevalence of the bullying phenomenon among primary school students, we used the Adolescent Peer Relations Instrument Bully-Target (APRI-BT), developed by Parada (2000) and validated on the Romanian school population by Balan et al. (2022). The APRI-BT consists of 36 items designed to assess bullying and victimization in all three forms (physical, verbal, social). Responses are measured on a 6-point Likert scale, where: 1 = never, 2 = sometimes, 3 = once or twice a month, 4 = once a week, 5 = several times a week, 6 = daily. The scoring process yielded separate scores for each form of bullying, each form of victimization, as well as a total for bullying behavior and one for victimization experience. The internal consistency of the scales ranges from 0.809 to 0.941.

Data analysis

The statistical analyses were performed using IBM SPSS Statistics version 20. A frequency analysis was conducted to identify the distribution of roles involved in the bullying phenomenon: uninvolved, victim, perpetrator, bully-victim.

RESULTS

As shown in Table 1, our research indicates that, across the entire sample, 48.3% (170) of students are uninvolved in the bullying phenomenon, 28.7% (101) are victims, 6.5% (23) are perpetrators, and 16.5% (58) are bully-victims.

For the group of boys, the results show that 46.6% (81) are uninvolved, 28.2% (49) are victims, 7.5% (13) are perpetrators, and 17.8% (31) are bully-victims.

For the group of girls, we observed that 50% (89) are uninvolved, 29.2% (52) are victims, 5.6% (10) are perpetrators, and 15.2% (27) are bully-victims.

Table 1. The distribution of roles involved in the phenomenon of bullying

ROLE	TOTAL		BOYS		GIRLS	
	n	%	n	%	n	%
Uninvolved	170	48.3%	81	46.6%	89	50%
Victim	101	28.7%	49	28.2%	52	29.2%
Perpetrator	23	6.5%	13	7.5%	10	5.6%
Bully-victim	58	16.5%	31	17.8%	27	15.2%

DISCUSSION

Our study shows that 28.7% of the participants are victims, 6.5% are perpetrators, and 16.5% are bully-victims. The percentage of students in a secondary role, classified as uninvolved, is 48.3%.

Gano-Overway (2013) identified a prevalence of 39% for victimization and 23% for bullying perpetration in a sample of 528 participants aged between 10 and 15 years. In our research, the prevalence is lower. The differences between studies can be explained by the frequency threshold used in case inclusion.

While in our study the responses considered ranged from at least once or twice a month to daily within the last two months (approximately, based on the school period during which the assessment was conducted), in that study all reported responses from at least once in the past month were included. The stricter threshold applied in our study may lead to a lower prevalence. This choice was based on one of the defining characteristics of bullying, namely repetition.

Gomes et al. (2022) found in a sample of 1,147 primary school students that 28.86% reported being victims, 6.89% reported being perpetrators, and 41,41% reported being bully-victims. We can observe percentages similar to those in our study regarding the roles of victim and perpetrator. However, the percentage of bully-victims is much higher in this study, a fact attributable to the methodology used.

Benítez-Sillero et al. (2024) reported a prevalence of 26% in a sample of 958 subjects aged between 12 and 18 years. In this study, the prevalence of victimization was 18%, the prevalence of bullying perpetration was 2%, and the percentage of those involved in both roles was 6%. A prevalence of 74% was identified among uninvolved students.

Thus, we can observe that our results indicate a higher prevalence regarding involvement in primary roles and a lower percentage of students involved in secondary roles. In both studies, approximately the same reference period (2 months) and a frequency threshold of at least once or twice a month were considered. Our results may suggest a higher prevalence, whether real or perceived differently, which can be explained by the different cultures to which the subjects belong. Romania is characterized by a predominantly collectivist culture, while Spain by an individualist culture. The prevalence of bullying perpetration is higher in countries with a collectivist culture, whereas the prevalence of victimization is higher in countries with an individualist culture. In countries characterized by individualism, girls experience victimization more frequently and are more likely to perpetrate social bullying, while boys are more involved in both dimensions of physical bullying (Felix & Green, 2010 cited by Balan et al., 2022). In countries characterized by collectivism, the percentage of victimization through all forms of bullying is higher among boys (Ji et al., 2016 cited by Balan et al., 2022).

According to the National Public Health Report on Children and Youth in Romania (2016), the prevalence of victimization recorded at the national level is 17.9%, while in Moldova it is 18%. Thus, we can note a higher prevalence in our research, which may suggest that, at the national level, the phenomenon has increased in recent years.

The study conducted by Cosma et al. (2015) shows that, at the national level, approximately 13.9% of girls and 19.8% of boys were victimized. Moreover, 20.6% of girls and 30.8% of boys perpetrated bullying.

In our study, the percentage of girls (29.2%) in the victim role is slightly higher compared to that of boys (28.2%), which contrasts with the results of the previous study. In addition, the prevalences identified in our sample are considerably higher. The percentage of boys in the perpetrator role (7.5%) is greater than that of girls (5.6%), which is consistent with the findings of the aforementioned research. However, significant differences can be observed regarding incidence, differences that can be explained at least partially by the fact that the previous study evaluated only the roles of victim and perpetrator, whereas our research also included the bully-victim role, with 17.8% of boys and 15.2% of girls falling into this category.

CONCLUSIONS

This research aimed to determine the prevalence of the bullying phenomenon among primary school students, with a focus on the distribution of roles, as well as the identification of gender differences.

Our study illustrated a high prevalence of involvement in bullying, confirming the magnitude of the phenomenon even at this age. The gender-based distribution revealed small differences, suggesting that bullying represents a problem common to both genders.

These findings support the importance of including anti-bullying intervention programs starting from the primary school level. Bullying is a cyclical phenomenon in which various forms of abusive behavior are perpetuated and tolerated within the social interactions among students – in our case, within a collectivist culture. Therefore, intervention programs could adopt an integrative perspective, focusing on all the roles involved in this abusive cycle.

AUTHOR CONTRIBUTIONS

A.-M. STICEA and A. COJOCARIU contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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EFFECTS OF A STRUCTURED PHYSICAL EXERCISE PROGRAM ON THE DEVELOPMENT OF MUSCULAR STRENGTH IN PRISON POPULATIONS

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ABSTRACT. Physical inactivity represents a major concern in prison environments, where limited movement opportunities contribute to decreased physical fitness and muscular strength. Structured exercise programs can mitigate these negative effects and support inmates' overall health and rehabilitation. The study aimed to evaluate the effects of a structured physical exercise program on the development of muscular strength among incarcerated individuals, emphasizing its potential contribution to physical and psychological well-being. Sixty male prisoners participated and were randomly divided into an experimental group and a control group. The experimental group followed a four-month structured exercise program with four sessions per week, progressing through stages of anatomical adaptation, calisthenics for hypertrophy, circuit strength training, and high-intensity anaerobic exercises. Exercises such as push-ups, sit-ups, and squats were used. Muscular strength was measured before and after the intervention. The results indicated significant improvements in muscular strength within the experimental group, while the control group showed no relevant changes between pretest and posttest assessments. These findings demonstrate that a structured physical exercise program effectively enhances muscular strength and overall physical condition, supporting its implementation as a key component of health promotion and rehabilitation initiatives in correctional settings.

Keywords: motor activity;muscular tone; physical education; rehabilitation

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INTRODUCTION

The prison environment is characterized by constant conflicts, influenced by antisocial behavior, the homogenization of individuals, and the alignment of legislation with prison realities. Education and structured activities in prisons facilitate inmates' reintegration into society and enhance the effectiveness of penal sanctions. Incarceration also induces changes in personality and behavior.

The penitentiary system operates on fundamental principles, including respect for human dignity, the guarantee of prisoners' rights, and preparation for social reintegration. Prisons provide spaces for individual and group sports to maintain physical and mental fitness. Participation is based on health status, skills, age, and preferences. Sports activities promote physical and mental health, discipline, teamwork, and reduce stress and violent behaviors. Empirical studies show that many inmates have low education levels and lack qualifications (Morgan & Liebling, 2007; Combessie, 2001).

Physical strength—the ability of the musculoskeletal system to generate tension and overcome resistance—is fundamental to overall health (Haff & Triplett, 2015). Exercises like squats, sit-ups, and pull-ups improve muscular endurance, joint mobility, and body control while enhancing self-esteem and self-efficacy (Bandura, 1997). Strength training also reduces aggression and regulates stress hormones, providing a safe outlet for energy and improving social and emotional development (Fenske, 1982; Meek, 2013; Frigout, Degrenne, & Delafontaine, 2020).

This study aims to analyze the effects of a structured physical exercise program on muscular strength in inmates, highlighting its potential to counteract the negative effects of inactivity.

The research hypotheses are:

1) participation in a strength program improves muscular endurance (push-ups, sit-ups, squats) in the experimental group compared to controls;

2) participation correlates with a significant increase in muscular endurance among participants.

MATERIAL AND METHODS

Participants

The study received approval from the Ethics Committee (no.6981/06.02.2024), and written informed consent was obtained from all participants prior to inclusion in the study. The sample consisted of 60 male inmates, divided equally into two groups: an experimental group (n = 30) and a control group (n = 30).

· **Experimental group (n = 30):** Participants enrolled in a structured physical education program.

· **Control group (n = 30):** Participants who did not receive any physical activity intervention.

Both groups were comparable in terms of socio-demographic characteristics, types of committed offenses, and disciplinary sanctions received. The experimental group consisted of male inmates convicted of violent offenses, with a mean age of 34.9 years (range 22–49). The distribution of offense types was: homicide and attempted homicide – 36.7%, aggravated assault – 26.7%, armed robbery – 23.3%, sexual assault or rape – 13.3%. The control group had a mean age of 34.5 years with a similar range, and all participants were male and convicted of violent crimes. Offense distribution was comparable: homicide and attempted homicide – 33.3%, aggravated assault – 30%, armed robbery – 20%, sexual assault or rape – 16.7%.

Procedure

All participants were assessed at two time points: pretest (before intervention) and posttest (after completing the physical education program). Measurements included somatometry, bioimpedance, postural assessment, strength tests, isometry, and mobility evaluation. The experimental group participated regularly in supervised physical training for four months, four sessions per week, while the control group did not engage in any intervention.

Intervention Program

The physical activity program lasted four months with four weekly sessions for the experimental group. Initial and final assessments were conducted, including somatometry, bioimpedance, postural analysis, strength tests, isometry, mobility, and explosive strength.

Program Structure:

1. **Week 1 – Initial Assessment:** Somatometry, strength, isometry, and mobility tests.
2. **Weeks 2–3 – Anatomical Adaptation:** Development of mobility and learning basic exercises (squats, lunges, push-ups, pull-ups, trunk extensions/flexions), breathing and coordination exercises, low- to moderate-intensity aerobic training (60–70% of max HR).
3. **Weeks 4–7 – Calisthenic Training for Hypertrophy:** Bodyweight exercises with adaptive progressions and regressions.
4. **Weeks 8–11 – Circuit Strength Training:** Consecutive exercises without breaks, only short transitions between exercises.

5. **Weeks 12–14 – High-Intensity (Anaerobic) Training:** Complex exercises to develop strength and cardiovascular capacity, with heart rate >75% of max HR.
6. **Week 15 – Active Recovery and Aerobic Exercises:** Light activities to recover and prepare for final testing.
7. **Week 16 – Final Assessment:** Repeat all initial evaluations to compare results.

Equipment Used

The equipment used in the study included a stopwatch, a Myotest device, and basic tools necessary for monitoring the execution and timing of exercises. These instruments allowed accurate measurement of performance parameters during the testing sessions and training program.

Test Battery: The assessment protocol focused exclusively on evaluating strength and muscular endurance. The strength component included exercises such as push-ups, sit-ups, and squats, performed according to standardized testing procedures. Isometric endurance was measured through wall-sit and forearm/plank support tests. Muscular endurance was assessed using three validated tests: push-ups, sit-ups, and squats performed in 30 seconds, following the Eurofit (1988) and Suni et al. (1996) protocols. All tests were applied under consistent conditions, both during the initial and final evaluations, to ensure the reliability and comparability of the results.

RESULTS

The first hypothesis proposed that the experimental group would demonstrate a significant increase in physical performance indicators from pretest to posttest compared to the control group. Participants were divided into two groups: an experimental group, which participated in the structured physical training program, and a control group, which did not receive any intervention.

Muscular endurance and strength were assessed using three standardized tests: push-ups, sit-ups, and squats, applied before (pretest) and after (posttest) the implementation of the program.

The results show significant improvements for all three tests in the experimental group: push-ups ($M_{pre} = 30.00 \pm 3.20$; $M_{post} = 42.00 \pm 4.10$; $t(29) = -18.6$, $p < 0.001$), sit-ups ($M_{pre} = 29.00 \pm 2.90$; $M_{post} = 40.00 \pm 3.80$; $t(29) = -16.9$, $p < 0.001$), and squats ($M_{pre} = 24.00 \pm 2.50$; $M_{post} = 34.00 \pm 3.20$; $t(29) = -14.7$, $p < 0.001$).

Table 1 summarizes the comparisons between groups, highlighting that posttest performance differences between the experimental and control groups are substantial, confirming the impact of the program on physical indicators.

Table 1. Comparative Table Between Groups (Pretest vs Posttest)

Test	Pretest (M±SD)	Posttest (M±SD)	Difference	t(29)	p
Push-ups	30.00 ± 3.10	30.20 ± 3.00	0.2	−0.85	0.40
Sit-ups	29.00 ± 3.00	29.10 ± 2.90	0.1	−0.77	0.45
Squats	24.00 ± 2.40	24.10 ± 2.50	0.1	−0.68	0.50

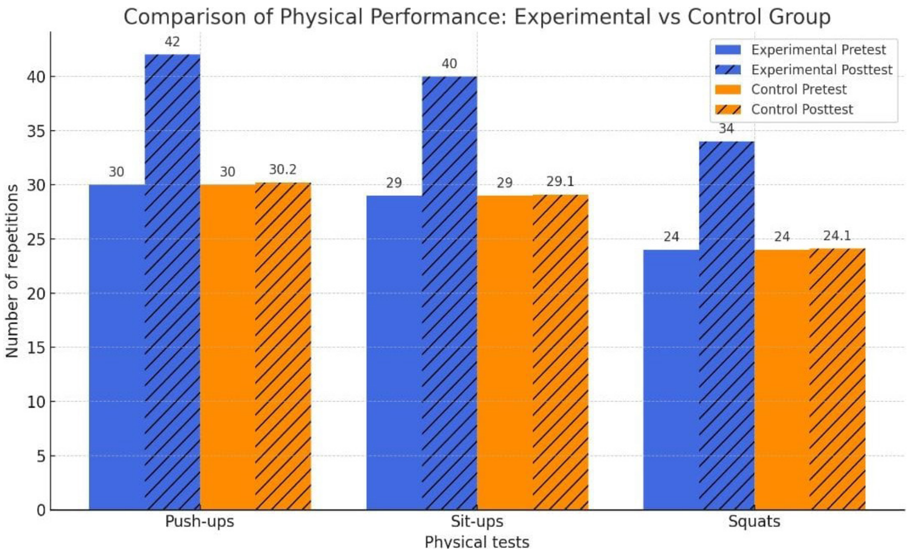

Fig. 1. Evolution of Strength in the Two Groups

These improvements are not explained only by physical exercise but also by psychosocial and contextual mechanisms. Participation in structured training promotes self-efficacy and a sense of competence, fundamental concepts in sports psychology and Bandura's theory (1997). This confirms the effectiveness of the program on muscular endurance and strength and indicates that improvements are directly linked to the intervention.

The observed benefits are supported by literature on neuromuscular and physiological adaptations to resistance exercises (ACSM, 2009; Eime et al., 2013; Fox, 2000). In the penitentiary context, these adaptations positively influence quality of life, mobility, discipline, and indirectly, psychological health. The applied physical program had a significant and complex impact on participants, combining physiological, psychological, and social effects. These data support the implementation of structured training programs in prison settings to enhance not only physical health but also psychological balance and social adaptation.

The second hypothesis assumed that participation in the strength program correlates with a significant increase in muscular endurance (push-ups, sit-ups, squats) among inmates. To assess the program's effect on physical performance, correlations between improvements in the three tests were analyzed.

Table 2. Correlation Between Strength Test Improvements – Experimental Group

Variables	ρ (Pearson)	p (Significance)
Push-ups – Sit-ups	0.987	< 0.001
Push-ups – Squats	0.981	< 0.001
Sit-ups – Squats	0.975	< 0.001

The correlation coefficient ($\rho = 0.975–0.987$, $p < 0.001$) indicates a very strong positive association between improvements in different muscular endurance tests. This suggests that progress in one test is closely associated with progress in the others, confirming the overall impact of the program on inmates' physical performance.

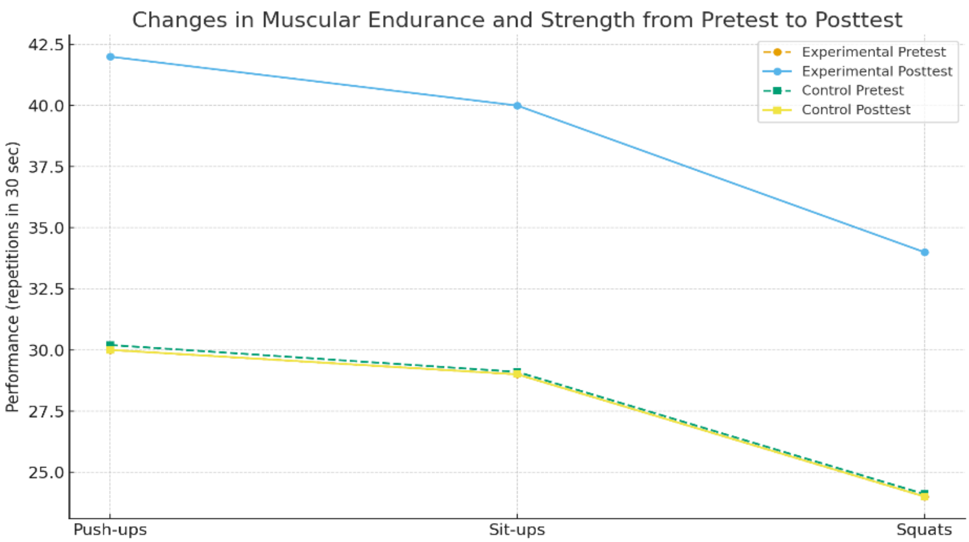

Fig. 2. Muscular endurance and strength in the experimental group from pretest to posttest

Figure 2 shows the increase in muscular endurance and strength in the experimental group from pretest to posttest. Performance evolution demonstrates consistent and uniform improvements across all three tests. Organized physical activity induces significant physiological adaptations, including enhanced neuromuscular coordination, more efficient motor unit recruitment, and muscle fiber hypertrophy, contributing to increased endurance and strength (ACSM, 2009). These adaptations directly affect functional capacity, mobility, and balance, which are essential for maintaining physical health and preventing maladaptive behaviors during incarceration.

DISCUSSION

The present study aimed to evaluate the impact of a structured sports program on inmates, focusing on the degree of improvement in physical performance. The results provide a comprehensive view of how physical activity can produce both immediate effects and long-term implications for personal development and social adaptation in the prison environment.

From the perspective of physical performance, the results are conclusive and significant. The experimental group demonstrated substantial improvements in all strength and muscular endurance tests, while the control group did not show notable changes. This confirms that the sports program was directly responsible for the increase in physical capacity. Enhancements in muscular strength and endurance contribute not only to physical health and the prevention of medical issues associated with sedentary behavior but also to the improvement of quality of life during incarceration, enhancing mobility, balance, and overall well-being.

Moreover, better physical performance may have indirect psychological effects, such as increased self-confidence, reduced frustration, and the development of a positive daily routine within the penitentiary setting. These structured activities provide a healthy routine, fostering discipline, self-reflection, and self-efficacy, which are essential for future social reintegration.

The study confirms that structured sports programs represent an effective strategy for promoting both psychological and physical health among inmates.

When compared with findings from the existing literature, the present results align closely with previous research emphasizing the positive effects of structured exercise interventions in prison settings. Battaglia et al. (2015) demonstrated that organized physical activity significantly improves inmates' fitness levels, emotional stability, and psychosocial well-being. Similarly, Oh et al. (2021) found that high-intensity circuit training in a German correctional facility produced marked improvements in physical performance, particularly in strength and endurance, confirming the adaptability of such interventions even in restrictive environments. These outcomes are consistent with the improvements observed in the current study following a progressively structured calisthenic training program.

Comparable findings were also reported by Zubala et al. (2014), who noted that regular, organized exercise sessions—lasting 90 minutes, three times per week—significantly enhanced both fitness and health outcomes among incarcerated populations compared to a control group engaging only in light activity. The present data corroborate these results, suggesting that even within limited prison conditions, systematic and progressive training can yield substantial physiological benefits.

When compared with non-incarcerated populations, studies on bodyweight training have demonstrated similar trends. Calatayud et al. (2019) reported that both traditional and plyometric push-up training produced significant increases in muscular strength and endurance within short intervention periods. Although the current program did not include plyometric exercises, the magnitude of improvement observed in push-ups, sit-ups, and squats supports the view that structured, bodyweight-based training elicits meaningful neuromuscular adaptations regardless of population context.

The present findings therefore expand current evidence by demonstrating that a multi-stage, calisthenic-based training program can be effectively implemented within correctional institutions, producing outcomes comparable to those achieved in non-restricted populations. However, it is plausible that certain contextual factors—such as limited nutritional quality, psychological stress, or lack of autonomy—might attenuate maximal performance gains relative to free-living individuals. Future studies could further examine the moderating effect of environmental and psychosocial factors on physical adaptation in prison settings, as well as directly compare the effects of identical interventions across incarcerated and non-incarcerated groups.

CONCLUSIONS

The implementation of a structured sports program within the prison context led to measurable improvements in inmates' physical performance. The experimental group achieved significant gains in strength and muscular endurance, whereas no notable changes occurred in the control group. These results indicate that such programs are effective in enhancing physical capacity, promoting overall health, and supporting personal development.

Furthermore, the program contributed to psychological well-being by fostering self-confidence, discipline, and the adoption of positive routines, which may facilitate social reintegration after release. This study provides evidence that structured physical activity is a valuable intervention in correctional settings, supporting the inclusion of sports programs as a standard component of inmate rehabilitation.

Future research could explore the long-term effects of structured sports programs on recidivism, social behavior, and psychological resilience. Additionally, combining physical training with complementary interventions, such as educational or vocational programs, may further enhance the holistic development of inmates.

AUTHOR CONTRIBUTIONS

All authors contributed to the design and implementation of the research, the collection and analysis of data, and the interpretation of the results. Additionally, all authors participated in the writing and revision of the manuscript. All authors have read and approved the final version for publication.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to the research, authorship, or publication of this manuscript.

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THE INFLUENCE OF AGE AND REACTION TIME ON SPRINT PERFORMANCE: AN ANALYTICAL STUDY ACROSS THE LAST FIVE EDITIONS OF WORLD ATHLETICS CHAMPIONSHIPS

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ABSTRACT. ***Introduction:*** Sprinting performance has been shown to depend on multiple physiological variables, among which age and start reaction capacity may exert a major influence. Since hundredths of a second can decide the outcome of sprint races, understanding these factors has been considered essential. ***Objective:*** This study aimed to examine the relationships between athletes' age, reaction times at the start, and sprint performance, based on data from the last five editions of the World Athletics Championships. ***Materials and Methods***: Official data on age, reaction times, and final results of athletes who competed in the 100 m and 200 m events (male and female) were collected and processed. Correlation statistical analyses were performed to identify potential associations between the studied variables. ***Results:*** Preliminary results showed a trend of increasing reaction times with age, as well as an association between faster reaction times and superior sprint performance. ***Discussion:*** These findings were consistent with previous studies that reported an association between increasing age and a progressive decline in reaction speed and sprint performance (Collet, 1999; Tønnessen et al., 2013; Haugen et al., 2019). Those studies showed that athletes typically reached peak sprint performance between the ages of 20 and 27, after which reaction times tended to increase, and maximal sprinting speed gradually declined. ***Conclusions:*** Age and reaction time appear to be relevant predictive factors for sprint performance and should be considered in the selection and training strategies of elite athletes.

Keywords: World championship, speed, athletics, reaction speed, age of peak

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INTRODUCTION

Sprinting widely used to benchmark neuromuscular capacities and maximal-speed technique offers a privileged setting to study performance determinants in elite competition. Among proximal outcome variables, start reaction time and athletes' age are consistently cited as key factors, acting either as direct predictors or as moderators of the strength speed to performance pathway (Valamatos et al., 2022; Harnish & Greer, 2025). Clarifying how these variables operate independently and in interaction can sharpen performance models and inform decisions on selection, periodization, and career management in high-level sprinting (Turner et al., 2025).

Peak age in sprinting generally falls in the mid-20s, with nuances by event and gender. Contemporary analyses of developmental trajectories and percentile distributions indicate that, in the 100 m, men attain optimal age slightly earlier than women, while in the 200 m and 400 m women peak a bit later (Agudo-Ortega et al., 2024). Broader reviews spanning the sprint - endurance continuum corroborate that speed - power sports peak earlier than endurance sports, with potential shifts linked to training evolution and competitive context (Harnish & Greer, 2025). These patterns align with recent syntheses on what differentiates elite performers in ≤400 m events, where biomechanical, physiological, and technical parameters are tied to success at major championships (Turner et al., 2025).

Start reaction time constrained by World Athletics' 0.100 s threshold for signaling a start before the gun remains a critical element of performance, particularly in the 100 m and 110/100 m hurdles (World Athletics, 2024). Although this threshold is a technical convention, debate persists over its validity and implementation, as micro-variations in equipment, block settings, and competition conditions can shift the distribution of recorded times (Valamatos et al., 2022). Post 2020 analyses drawing on World Championship data report robust associations between faster reactions and better final times, with gender and event specific differences (Pavlović, 2021; Zhang, 2021). Studies covering recent world level competitions, including indoors, show event-specific reaction time distributions (e.g., contrasts between 60 m and 400 m and between semifinal/final rounds) (Đukić et al., 2023/2024). Longitudinal examinations of Olympic series (2000 - 2020) likewise confirm consistent correlations especially in women's events underscoring the competitive importance of reaction time (Biswas & Bandyopadhyay, 2023). Analytical summaries for the 2022 - 2023 seasons note clustering at lower (faster) reaction values than in prior editions, plausibly reflecting athletes' adaptations and instrumentation differences, without diminishing the practical salience of start reaction in the performance equation (Valamatos et al., 2022).

The World Athletics Championships provide an ideal environment to analyze links among age, reaction time, and results due to standardized timing and sizable elite samples. The last five editions London 2017, Doha 2019, Eugene 2022, Budapest 2023, and Tokyo 2025 form a strong comparative base across continents, instrumentation setups, and micro-climates, while maintaining consistency in start rules and technical protocols (World Athletics, 2025; Olympian Database, 2025). Pragmatically, this 2017 - 2025 window also captures current cohorts' maturation, spanning rising athletes and those at or beyond peak age, enabling modeling of performance curves versus chronological age and neuromuscular reactivity indicators.

Biomechanical syntheses highlight the block push-off phase, functional asymmetries, and time to initial force factors functionally linked to measured reaction time (Valamatos et al., 2022). Complementarily, meta-analyses on post-activation performance enhancement (PAPE) suggest that targeted warm-up/conditioning can acutely modulate components relevant to the start and early acceleration, even though most evidence derives from non-competition contexts (Loturco et al., 2024). Recent predictive models for the 100 m further partition the contributions of start, acceleration, and maximal-speed phases, enabling finer estimation of how reaction time differentiates athletes amid technological and training advances (Kotuła et al., 2025).

Despite studies correlating reaction time and performance across multiple years, a gap remains: few post-2020 investigations integrate age, reaction, and final performance across the last five World Championships using a single official source (World Athletics Results) and constant technical rules. Moreover, potential age and reaction interactions (whether athletes just below or above peak age compensate via superior start reactivity) and round effects (heats, semifinals, finals) are still under quantified in comparative, inter-edition analyses (Pavlović, 2021; Đukić et al., 2023/2024).

The current research is thus justified as a comparative, multi-edition analysis with official data and replicable procedures aimed at: quantifying separate and joint effects of age and reaction on results; testing interaction terms (e.g., reaction result slopes moderated by age); mapping differences by event (100 m, 200 m, 400 m), gender, and competition phase; and generating practical recommendations for selection, planning, and race strategy (e.g., estimating how much 0.01 s in reaction "matters" by event and age). Integrating the 0.100 s rule (World Athletics, 2024) ensures interpretation within a regulated framework, reducing confusion between true reactivity differences and measurement artifacts.

Finally, the 2017 - 2025 period coincides with densification at the top of world sprinting and extended standardization of timing and block systems, alongside increased availability of official datasets (World Athletics, 2023; World Athletics, 2025). This enhances statistical robustness and external relevance for coaches prioritizing interventions with higher expected impact (optimizing pre-start protocols for athletes near the upper bound of peak age). Building on these premises, the present study aims to: analyze the age - performance relationship in sprint events; assess the impact of start reaction time on final results; and identify age and reaction interactions within sprint performance - thereby informing age-aware preparation, adaptive training strategies, and maximization of start performance - using data from competitions of high international visibility and relevance.

The hypotheses of this research are as follows:

We assume that athletes' age has a significant relationship with sprint performance, with optimal times recorded around peak age (24 - 27 years) and a tendency for performance to decline at older ages.

We assume that start reaction time significantly influences the result, with athletes who react faster achieving better final times—especially in the 100 m and 200 m, where the start phase plays a decisive role.

We consider that there is an interaction between age and reaction time, such that the effect of reaction time on performance varies depending on the athlete's age.

MATERIALS AND METHODS

Participants

The study population consisted of athletes competing in sprint and hurdles events (100 m, 200 m, 400 m men and women; 110 m hurdles men; 100 m hurdles women; 400 m hurdles men and women) at the last five editions of the World Athletics Championships (2017 London, 2019 Doha, 2022 Eugene, 2023 Budapest, 2025 Tokyo).

Only athletes for whom complete data were available on age (years), start reaction time (s), and final time (s) were included in the analysis.

Inclusion criteria: athletes officially validated by World Athletics, with complete data for the variables listed above.

Exclusion criteria: disqualifications for false start (reaction time < 0.100 s), withdrawals, or missing data.The size of the participant pool varied by edition. In a single edition, the number of unique athletes entered across the 10 events analyzed was approximately 470 - 510, which over the five editions corresponds to a total of 2,350 - 2,550 unique athletes (central value approx. 2,450).

With regard to actual participations (across all rounds: heats, semifinals, finals), the same athlete could compete 2 - 3 times in an event; the average number per edition was 750 - 800 participations. Therefore, for all five editions combined, the estimated total is 3,750 – 4,000 actual participations (central value approx 3,875).

Procedure

Data were retrieved from publicly accessible official World Athletics databases and organized into a tabular dataset (Excel). They were then imported into specialized statistical environments for processing (IBM SPSS Statistics v.29 and R v.4.3). Prior to analysis, consistency checks were performed, and the database was cleaned by removing incomplete records.

Materials Used

Only official competition data (World Athletics Results), published after each World Athletics Championships edition, were used. Timing equipment and electronic starting-block systems were standardized by the organizers and complied with World Athletics rules, which define the start reaction threshold (0.100 s). For data processing and analysis, the following were used; Microsoft Excel 365 software for centralizing raw data; IBM SPSS Statistics v.29 and R v.4.3 software for statistical analyses; units of measurement consistent with the International System (seconds for times, years for age).

Data Analysis

The analysis was carried out on two complementary datasets:

Unique-athlete group, comprising approximately 2,350 - 2,550 athletes entered in the 10 events over the five editions (central value approx. 2,450). This dataset was used to evaluate the relationship between athletes' age and performance, since each athlete was considered only once per event.

Actual-participations group, comprising approximately 3,750 - 4,000 participations across all rounds (heats, semifinals, finals) of the five editions (central value approx. 3,875). This dataset enabled a detailed analysis of reaction times and performance by competition phase.

We ran a one-way ANOVA across age groups (<23, 23 - 27, >27), ignoring competition/year, to test whether finish time and reaction time differ by age; we report F, p, n^2, and descriptives, and used Tukey HSD when at least three groups were available.

We computed Pearson correlations between age and finish time, age and reaction time, and reaction time and finish time, reporting r (strength and direction), p, and N for each event and sex, with a separate sheet listing significant correlations.

RESULTS

In the women's 100 m, differences among the <23, 23 - 27, and >27 age groups are statistically significant ($p = 0.00003$, $n^2 = 0.055$): women over 27 reach the finish first, around 11.241 s, while those under 23 trail slightly at about 11.602 s. In the men's 100 m, the picture is even more clear-cut ($p < 0.00001$, $n^2 = 0.061$): the "golden" age appears to be 23 - 27 years, with 10.281 s, whereas those under 23 bring up the rear at approximately 10.552 s. In the men's 110 m hurdles, it is not the final time but the start that makes the difference: reaction times vary significantly ($p = 0.00036$, $n^2 = 0.047$), with athletes over 27 the quickest off the gun (0.145 s) and the 23 - 27 group reacting the slowest (0.156 s). In the men's 400 m, the age effect exists but is modest ($p = 0.019$, $n^2 = 0.021$): athletes over 27 record the best averages, around 45.250 s, while those under 23 remain at about 45.631 s. And in the women's 400 m hurdles, the same modest yet significant pattern repeats ($p = 0.019$, $n^2 = 0.022$): athletes over 27 dip toward 55.172 s, whereas those under 23 average around 55.869 s. Overall, age matters - especially in short sprinting and in reaction time for hurdles - but the effect is generally small to moderate, indicating that the remaining differences are driven by training, technique, and current form.

Table 1. One-way ANOVA across age groups (<23; 23 – 27; >27) for each event, analyzed separately by gender

Event	Gender	Variable (sec)	F	P	N²
100m	Women	final time	10.675	*0.000031	0.055
100m	Men	final time	13.038	*0.000003	0.061
110m hurdles	Men	reaction time	8.129	*0.000357	0.047
400m	Men	final time	4.005	*0.019032	0.021
400m hurdles	Women	final time	4.001	*0.01915	0.022

**Significant differences, p< .05*

Looking across all events together, when the start is slower, the final time also tends to be poorer. The relationship between reaction time and result is positive in several events—men's 100 m, men's 110 m hurdles, 200 m (mixed set), as well as women's 400 m and women's 400 m hurdles (r roughly between 0.13 and 0.19). In other words, every hundredth lost at the gun shows up, to a small extent, at the finish. Age enters the equation with an effect in the expected direction: as athletes are more mature, final times tend to be slightly better. This is evident in the women's and men's 100 m, the women's and men's 400 m, and the women's 400 m hurdles (small negative correlations, about −0.11 to −0.29). Moreover, where the relationship is clear, age comes with a better start as well: in the men's 110 m hurdles, older athletes react slightly faster (negative correlation between age and reaction time, r ≈ −0.166).

Overall, the effects are small in magnitude but consistent and practically meaningful: a better start helps almost everywhere, and competitive maturity yields, on average, a few hundredths in favor of the final time. The remaining differences are explained by training, technique, and current form.

More concretely, in the 100 m (women and men), 400 m (women and men), and women's 400 m hurdles, age shows small negative correlations with the result (r = −0.11…-0.29), meaning more mature athletes tend to record slightly better times. In magnitude, this corresponds to roughly 1 - 8% of the variance in times explained by age.

For reaction time, the relationship with age is not consistent: it was significant only in the men's 110 m hurdles (r ≈ −0.166, 3% variance), where older athletes react slightly faster; elsewhere, the association was not significant.

Reaction time correlates positively and significantly with the final result—that is, faster reactions are associated with better finishing times—in the men's 100 m (r = 0.165, p = 0.000245, N = 491), men's 110 m hurdles (r = 0.140, p = 0.011688, N = 324), 200 m (mixed; r = 0.130, p = 0.008865, N = 404), women's 400 m (r = 0.133, p = 0.007944, N = 396), and women's 400 m hurdles (r = 0.188, p = 0.000396, N = 351), with effects that are small but consistent.

Table 2. Pearson correlations between age, reaction time, and final time, by event and gender

Event	Gender	Variable	R	P	N
100m	Women	age_no. - result_sec.	-0.212	*0.000	371
100m	Men	reaction_sec. - result_sec.	0.165	*0.000	491
100m	Men	age_no. ↔ result_sec.	-0.207	*0.000	405
110m hurdles	Men	reaction_sec. - result_sec.	0.14	*0.011	324
110m hurdles	Men	age_no. - reaction_sec.	-0.166	*0.002	335
200m	Mixt	reaction_sec. - result_sec.	0.13	*0.008	404
400m	Women	reaction_sec. - result_sec.	0.133	*0.007	396
400m	Women	age_no. - result_sec.	-0.285	*0.00	396
400m	Men	age_no. - result_sec.	-0.153	*0.003	370
400m hurdles	Women	reaction_sec. - result_sec	0.188	*0.000	351
400m hurdles	Women	age_no. - result_sec.	-0.109	*0.041	351

**Significant differences, p< .05*

In the women's 100 m (result), there are two significant differences: >27 is faster than <23 by 0.361 s (p = 0.0126), and 23 - 27 is faster than >27 by 0.351 s (p = 0.0089), which orders the groups as follows: 23 - 27 (fastest) < >27 < <23.

In the men's 100 m (result), 23 - 27 outperforms <23 by 0.271 s (p = 0.0003), and >27 outperforms <23 by 0.240 s (p = 0.0046), so the order is 23 - 27 < >27 < <23.

For the men's 110 m hurdles (reaction time), >27 reacts faster than 23 - 27 by 0.012 s (p = 0.0002), and <23 is faster than 23 - 27 by 0.010 s (p = 0.0024); the resulting order of reaction times is: >27 (fastest) < <23 < 23 - 27.

Table 3. Significant Games - Howell comparisons between age groups, by event and gender

Event	Gender	Variable (sec)	Pair	Faster	P	N1	N2
100m	Women	Result	23 - 27 vs <23	23 - 27	0.008	162	79
100m	Women	Result	<23 vs >27	>27	0.012	79	130
100m	Men	Result	23–27 vs <23	23 - 27	0.000	199	109
100m	Men	Result	<23 vs >27	>27	0.004	109	97
110m hurdles	Men	Reaction time	23 - 27 vs >27	>27	0.000	175	94
110m hurdles	Men	Reaction time	<23 vs >27	>27	0.002	66	94

DISCUSSION

In summary, the post-2020 literature confirms the existence of a sprint performance peak around ages 24 - 27, with variations across events and genders (Agudo-Ortega et al., 2024; Harnish & Greer, 2025); the relevance of reaction time as a proximal determinant, with differences across events and rounds (Valamatos et al., 2022; Pavlović, 2021; Zhang, 2021; Đukić et al., 2023/2024); and the need for multi-edition analyses at the level of the World Athletics Championships to quantify interactions between age and reaction in relation to final performance (Turner et al., 2025; World Athletics, 2023). These findings motivate the present endeavor.

ANOVA results show small but consistent differences between age groups, with slightly better performances in the 23 - 27 and >27 categories. This pattern aligns with Haugen et al.'s (2018) large-sample analysis, which estimates the global sprint performance peak around ages 25 - 27, with variations by event and gender; in hurdles, the peak tends to occur slightly later for women, which is consistent with the fact that in our data the >27 group performed well in several events (e.g., 400 m and 400 m hurdles).

Earlier, Hollings, Hopkins & Hume (2014) reached a convergent conclusion—a peak-age window roughly between 23 - 28 years, with event-specific nuances. This provides an apt framework for the observation that differences between <23 and the more mature categories appear systematically (albeit with small effects).

At an even broader scale, work led by Berthelot (multi-disciplinary time-series analyses) shows that peak age in athletics gravitates around 26 years at the species/sport level, confirming that physical and neuromechanical maturation is reflected in maximal performances. This explains why, in our correlations, age - final time is negative (older age — lower time) in several events: the effect is real but small (small percentages of variance), exactly what we would expect when looking at data aggregated across many editions.

On the "start and reaction time" front, our data show that reaction correlates positively (but weakly) with the final result in a few events (men's 100 m, men's 110 m hurdles, mixed 200 m, women's 400 m, women's 400 m hurdles): faster reaction, a slightly better outcome. The biomechanical literature adds an important nuance here. Mero's classic review (1992) emphasized that, at the elite level, reaction time alone does not strongly predict performance; the real differences stem more from the power produced in the blocks, the orientation of force, and the coordination of acceleration. This fits what a small r (≈0.13 - 0.19) signifies—reaction matters, but it is not the major determinant.

Kinematic analyses. Slawinski et al. (2010) showed that elite sprinters differ from well-trained sprinters primarily in mechanical parameters of the block phase and the first steps (not in reaction per se). Likewise, Bezodis, Willwacher & Salo (2019) neatly synthesized that start performance depends on block positioning, horizontal force application, and contact times; reaction remains an important piece, but not the central one. These results explain why, in our correlations, r is positive but small: good sprinters don't win the race solely "at the gun" but through how they convert the start into efficient acceleration.

Beyond the start, for the 100 m (and, to a lesser extent, the 200/400), literature led by Morin and colleagues shows that the key determinant of performance is the force - velocity profile and the ability to orient the force vector forward during acceleration, which shortens ground contacts and increases step frequency. Our observation that a good reaction equals "a bit better at the finish", yet with a modest effect, is exactly what we would expect if the "true" performance lever is the mechanics of acceleration rather than reaction time per se.

CONCLUSIONS

This study examined relationships between age, start reaction time, and sprint performance across the last five World Athletics Championships (2017 - 2025). Using official datasets and standard procedures, we analyzed age-group differences, correlations among key variables, and event- and sex-specific patterns.

Age shows small-to-moderate but consistent associations with results. In the 100 m, the peak-age group (23 - 27) is fastest in both women and men: for women, 23 - 27 is faster than >27 by 0.351 s ($p = 0.0089$) and >27 is faster than <23 by 0.361 s ($p = 0.0126$), ordering the groups 23 – 27, >27, <23; for men, 23 - 27 outperforms <23 by 0.271 s ($p = 0.0003$) and >27 outperforms <23 by 0.240 s ($p = 0.0046$), ordering 23 – 27, >27, <23. In longer sprints, older athletes sometimes hold the advantage (e.g., men's 400 m and women's 400 m hurdles), but effect sizes remain modest. Overall, age is a meaningful predictor, with peak performance typically near 23 - 27 years and event-dependent patterns beyond that band.

Faster starts are associated with better finishes, with significant positive correlations between reaction time and final time (i.e., slower start → slower finish) in men's 100 m ($r \approx 0.165$), men's 110 m hurdles ($r \approx 0.140$), 200 m (mixed, $r \approx 0.130$), women's 400 m ($r \approx 0.133$), and women's 400 m hurdles ($r \approx 0.188$). Effects are small but consistent, supporting the practical importance of reaction time while acknowledging that most variance lies in acceleration and max-speed mechanics.

Clear age differences in reaction times appear in the men's 110 m hurdles, where >27 react faster than 23 - 27 by 0.012 s ($p = 0.0002$), and <23 are faster than 23 - 27 by 0.010 s ($p = 0.0024$). However, the study did not explicitly model an age and reaction interaction (i.e., moderation of the reaction - result slope by age), so any interaction inference remains preliminary

AUTHOR CONTRIBUTIONS

Author 1, author 2, and author 3 contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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PARTICULARITIES OF PHYSICAL TRAINING FOR JUNIOR TENNIS PLAYERS: A LITERATURE REVIEW

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ABSTRACT. The modern high-performance tennis is characterised by intense dynamism. The players are required to think and act rapidly in order to apply their technical and tactical arsenal effectively in a multitude of competitive scenarios. Due to the increasing duration of matches, the large number of tournaments within a competitive season, and the diversity of playing conditions, athletes have to make exceptional physical and psychological efforts. This paper aims to present the primary aspects of physical training specific to tennis across the different stages of the junior period. Various studies highlight that well-structured physical training programs can significantly improve the speed and accuracy of technical execution by optimising the strength and endurance of relevant muscle groups. In tennis, better performance is closely correlated with implementing effective periodised training programs, adjusted to the age-specific characteristics of junior athletes. We focused on isometric power, muscle mass development, and force-generation capacity. Resistance training, when integrated into a structured, progressive program that targets both limb strength and core stability, is mandatory to increase stroke speed and overall sports performance. Therefore, we encourage coaches to integrate these physical training methods and perfect technical skills. The ultimate goal is to train complete athletes capable of performing effectively under high-stress conditions.

Keywords: tennis; physical training; strength; performance; juniors

INTRODUCTION

Although the training factors are closely interdependent, each is developed in a specific manner. Physical training represents the foundation upon which all other training components are built. The stronger the physical base, the greater the potential for developing technical, tactical, and psychological qualities.

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Sometimes, coaches fail to consider the strong correlation between physical and technical training. When the physical training foundation is inadequate, fatigue sets in quickly, and athletes struggle to make progress in other areas of their training. It is worth mentioning that physical training is the foundation of technical evolution, while technique is the most important element in acquiring and applying tactical skills in sport. As an athlete's physical condition improves, so do their technical and tactical capabilities, thus enhancing self-confidence and other psychological factors. In conclusion, physical training is the cornerstone on which all training components develop, ultimately enabling athletes to excel in sport (Bompa, 2021).

Generally, it is considered that for maximum physiological adaptation specific to athletic performance, an athlete should train for 8 to 12 years. Throughout all these years of practice, exercises are repeated systematically to promote adaptations that lead to better performance. When creating a training plan, a coach can choose from a wide range of exercises, selecting those that best fit the athlete's needs and the specific demands of the sport. Both general and specific exercises are included in the annual training program. However, their contribution to the overall plan varies according to the training cycle and the athlete's age (Gabbet & Kelly, 2008).

THE ROLE OF PHYSICAL TRAINING

Starting from a high level of the body's morphofunctional indices and the possibility to perform motor actions with high speed and power, while maintaining coordinated movements over extended periods, athletes can perfect the technical and tactical components depending on the requirements of performance sport. It is generally considered that the development of physical characteristics with age has a positive influence on the technical–tactical repertoire. However, recent research has shown that specific strength training can improve performance regardless of age (Bagis, 2020).

Studies have highlighted that including specific physical training can enhance both the speed and accuracy of technique by developing strength and muscular resistance in relevant areas (Kara et al., 2015). Coaches are encouraged to integrate these training methods alongside technical practice to train complete athletes who are able to perform effectively even under high stress (Myers et al., 2016).

Better tennis performance requires well-structured training plans that include working on isometric strength, muscle mass, and strength-generating capacity, all of them supported by proper monitoring and recovery (Fig. 1).

When incorporated into a periodised program and focused on limb strength and torso stability, resistance training routines plays a key role in improving serve speed and overall athletic performance (Ma et al., 2024).

Fig. 1. Physical training practice to develop isometric strength

A good technical repertoire in junior players is closely linked to their physical preparation. The research conducted by Filipčić et al. shows that junior players frequently take part in short rally exchanges, which highlights the importance of the efficiency of groundstrokes for those who wish to compete at high levels (Filipčić et al., 2021).

According to Fett et al., the requirements of modern tennis have made this sport increasingly competitive, thus forcing young athletes to perfect their playing technique in order to cope with the pressure specific to competitions (Fett et al., 2020). This growing intensity underscores the need for a specialised type of training that can enhance ball speed and stroke accuracy.

From a biomechanical point of view, performing effective strokes requires the correct use of body mechanics. For instance, the involvement of the lower limbs through knee and ankle flexion and extension plays a decisive role. Touzard et al. pinpoint that an efficient leg push motion is fundamental for powerful strokes, using efficient movements of the lower limbs (Touzard et al., 2023). This aspect is also supported by Myers et al. (2016), who emphasise that a strong and consistent stroke derives from a player's capacity to coordinate the movements of the torso and of the upper and lower limbs (Fig. 2).

Fig. 2. Specific physical training practice (Agility)

A study conducted by Ali and Supriono (2021) investigated the impact of physical fitness on the effectiveness of tennis serves, using a sample of 15 male players from the city of Jambi. The authors assessed several fundamental physical components (i.e., arm strength, back flexibility, and hand–eye coordination) through standardised tests. Their findings showed high performances in terms of strength and flexibility; however, serve performance was weak, with 67% of the players obtaining scores below the sufficient level. The study concludes that good physical fitness is mandatory for an efficient serve and recommends that training sessions should combine the development of technical skills with specific physical exercises; the goal is to improve players' performance in competitions.

Physical training is a vital aspect in improving stroke quality. Strength training exercises, in particular, have been shown to increase their velocity, with some studies reporting significant improvements in velocity after a six-week program (Kara et al., 2015). This type of program, which includes core-strengthening exercises and the use of medicine balls, led to a 4.9% increase in stroke speed among junior players (Kara et al., 2015).

Besides the physical components, mental elements such as focus and adaptability during play are highly relevant for junior players. Tactical awareness, including ball placement and service strategy, can influence performance to a great degree. For instance, using strategies such as serving to the opponent's weaker side can be more effective when players understand the dynamics of rallies (Fernández-Fernández et al., 2020).

Structural evaluations can identify essential performance indicators for strokes, which can guide training strategies focusing on the progress of junior players (Campos & Martínez-Gallego, 2024). The development of psychomotor and cognitive abilities plays a crucial role in on-court performance. It has been demonstrated that tests such as reaction time, intersegmental coordination, and hand–eye coordination are valuable tools for pointing out aspects to improve through specific training (Fig. 3). The results of such tests contribute to the creation of an individual performance profile; when continuously monitored, the profile helps to adapt training interventions. This complementary strategy is also suggested by Fernández-Fernández et al. (2014), who underscore the value of periodic physical testing in determining individual needs.

Fig. 3. Specific physical training practice for the speed for reaction and hand-eye coordination

In addition to psychomotor abilities, general strength training has become a significant pillar in the physical training of tennis players. Research studies carried out by Mengyao and Seung-Soo (2022) and Liu (2022) report that strengthening the core muscles optimises postural stability and supports the quick, explosive motions required for powerful and precise strokes. Furthermore, Arslan and Ergin (2022) highlight the positive impact of core strength exercises on agility and technical performance, which directly reflects in better abilities related to on-court dynamism.

The integration of strength training in the routines of junior players has been proven to improve technical execution. Research suggests that the implementation of resistance-based programs increases stroke speed more effectively than traditional training methods (Dewanti et al., 2020). This multifactor approach contributes significantly to the development of physical abilities necessary for efficient technique.

Incorporating physical performance testing provides an objective perspective on progress and helps identify correlations between physical variables and technical skills. Dobos (2018) reported significant correlations between speed, agility, and explosive strength and technical performance – a finding further supported by Shakir and Kadhum (2021), who emphasised the relationship between biomechanical angles and stroke power. This approach, through the detailed evaluation of physiological and biomechanical parameters, enables the optimisation of training plans and the continuous monitoring of performance improvements.

It is also essential to maintain a balance between training demands and recovery periods in order to avoid overexertion and injuries, which are frequent among young athletes. Data indicate an increased risk of injuries caused by the high intensity and frequency of power strokes performed both in training and in competition (Colomar et al., 2023). Therefore, the integration of appropriate recovery methods is essential for maintaining performance and longevity in this sport (Fleming et al., 2023).

In general, it is considered that intensive strength efforts are not recommended before the age of 10, as the morpho-functional structure is not yet sufficiently developed to support such efforts. Most specialists agree that at this age, the most suitable exercises are those involving free movements, where resistance is provided by the athlete's own body weight. According to Baroga (2002), children can safely start using light external weights around the age of eight. The author showed that, when done carefully and kept below 30% of body weight, weight training does not interfere with growth – in fact, it helps improve overall exercise capacity. At this age, however, isometric exercises are not recommended, as children tend to get tired quickly during static efforts. Instead, most specialists recommend developing the dynamic strength of the upper and lower limbs (Fig. 4), as well as strengthening the abdominal muscles (Pițu, 2016).

Fig. 4. Physical training practice for dynamic strength development

Strength and endurance are considered motor qualities that can be systematically developed, beginning around the ages of 8–9, with a positive evolution, and reaching their highest potential after full physical maturation. In contrast, according to the literature, speed and coordination can be effectively developed as early as ages 6–7. The functional support for speed development is provided by the high plasticity of the cerebral cortex specific to this age, as well as the predominance of cortical excitability phenomena.

Up to the age of 10, plyometric exercises are an ideal way of increasing the strength and agility of athletes while avoiding excessive efforts or the use of weights. The most efficient plyometric drills for tennis include short sprints – forward, backward, and to the side – over distances of 3–5 meters, combined with various jumping exercises (Marin & Ştefănică, 2023).

Regarding the improvement of coordination, according to Macovei (2016), training between the ages of 6 and 8 can effectively target spatial-temporal differentiation and coordination under time pressure. After the age of 8, coaches should focus on developing rhythm and reaction to visual and auditory stimuli.

In terms of flexibility, the most sensitive period for its development is considered the timeframe between 6 and 12 years. After the age of 12, joint range-of-motion improvements decrease dramatically unless special measures are taken during practices, and the differences between active and passive values also diminish considerably. Studies have shown that mobility develops most rapidly between the ages of 8 and 10 in the case of boys and between 9 and 11 in the case of girls (Polevoy, 2024). Starting with the age of 12, coaches must use mobility-centred structured training programs specific to tennis, in order to attain optimal performance and prevent mobility-related injuries (Macovei, 2016).

After the age of 12, the development of strength and endurance becomes the central aspect of practices, using physical training programs. Shi and Xuan (2023) showed that a 12-week rope-jumping training program can considerably improve strength, dynamic balance, and subsequently the stroke stability of junior tennis players. The authors mentioned above recommend using small loads and alternating landing stances while alternating the skipping rope methods (Shi & Xuan, 2023).

After the age of 16, the general guidelines include the use of periodised physical training practices and individualised physical training programs. Even though speed is a rather difficult motor quality to develop, at this age it can still be partially influenced by implementing appropriate means and methods (Simion, 2020). At this age, we can improve strength and endurance using training programs applicable to senior players. Regarding coordination, the focus will concern mainly the development of specific coordination through the practice of technical skills. Notable results can be obtained in the development of agility with the help of plyometric exercises, included in a physical training program lasting at least 12 weeks (Marin & Ștefănică, 2023).

Around the age of 16, functional training programs have also shown excellent results in improving the endurance necessary for tennis performance to the detriment of traditional endurance-oriented approaches (Xiao, 2024).

The development of mobility after age 16 varies considerably from one individual to another, depending on genetic factors, the subject's response the methods applied, and their overall health. When following a structured training program that included both dynamic and static stretching exercises, adolescents aged 16 showed significant improvements in mobility. However, the progress was more modest compared to that observed in younger participants aged 9–12 (Donti & Konrad, 2022).

CONCLUSIONS

The integration of strength training into the routine of junior tennis players has been shown to enhance technical performance, given that a solid technical foundation in young athletes is closely related to their physical training.

Between the ages of 6 and 10, coaches typically focus on developing speed and coordination, generally achieving very good results in improving these motor qualities. Research has also shown that mobility develops more effectively during this period than at later ages. Up to the age of 10, high-intensity strength efforts are not recommended, as the morphofunctional structure is not yet sufficiently developed to support such loads. Some authors consider that strength and endurance can be systematically developed only starting from the age of 8–9, having an upward evolution and maximum possibilities of improvement after the maturation of the body (Marin & Ștefănică, 2023). On the other hand, in this age range, bodyweight exercises and plyometric exercises can be successfully used to develop the power and agility of the athletes.

Regarding the age interval between 12 and 18, training should concern primarily strength and endurance, through systematic physical training programs. After the age of 15–16, the use of periodised and individualised training programs is recommended. While speed is one of the more challenging physical qualities to develop, it can still be partially influenced at this stage with the proper means and methods (Simion, 2020). Functional training programs have proven highly effective in building the endurance requested from tennis players, while mobility can continue to evolve through stretching exercises; however, results are usually lower than those recorded between the ages of 10 and 12 (Donti & Konrad, 2022).

AUTHOR CONTRIBUTIONS

Alexandru-Ilie Tudurache and Adrian Cojocariu contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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