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# EDUCATIO ARTIS GYMNASTICAE

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# Effect of Mixed Training Module on Key Physical Attributes of Sprinters

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**ABSTRACT. Introduction:** In university-level sprint training, athletes are often exposed to fragmented or non-systematic training approaches, which may limit the development of key physical attributes related to sprint performance. **Objective:** The present study aimed to examine the effects of a 12-week mixed module training programme (MMTP) on selected physical attributes and 100-m sprint performance in university-level sprinters. **Methods:** A quasi-experimental comparative design was employed. Twenty-eight male university sprinters (age: 20–25 years) were assigned to an experimental group (EG, n = 18) that followed the MMTP and a control group (CG, n = 10) that continued regular physical activity. Pre- and post-tests were conducted for 100-m sprint performance, vertical jump, standing long jump, 20-m sprint, and Illinois Agility Test. Data were analysed using analysis of covariance (ANCOVA). **Results:** After 12 weeks, the EG showed statistically significant improvements in 100-m sprint performance and all selected physical attributes compared with the CG ($p < 0.05$). **Conclusion:** The findings suggest that a structured mixed module training programme may be an effective applied approach for improving sprint-related physical attributes in university-level sprinters.

***Keywords:** Sprint performance; mixed training; explosive strength; agility; university athletes.*

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## INTRODUCTION

Sprint performance is a key determinant of success in track and field, and its development depends on multiple physical attributes such as speed, explosive strength, acceleration, and agility (Majumdar & Robergs, 2011). At the university level, sprinters often come from diverse training backgrounds and may not have consistent exposure to structured, long-term training programmes (Haugen et al., 2019).

In many university sport settings, particularly within developing sporting systems, training is frequently constrained by time availability, competition schedules, and access to facilities (Ndirangu et al., 2022). As a result, coaches often combine different training elements within a single programme to address multiple performance-related demands simultaneously (Oliver et al., 2024).

Previous research has demonstrated that combined training approaches—including strength training, plyometric exercises, sprint drills, and high-intensity interval training—can improve various performance characteristics in athletes (Aloui et al., 2021; Oliver et al., 2024; Yuan et al., 2024; Niering et al., 2025). Such approaches have been applied across different sports and competitive levels, showing positive effects on sprint speed, explosive power, and agility. However, most existing studies have examined specific combinations of training components or have focused on elite athletes or well-controlled laboratory-based settings (Kambitta Valappil et al., 2025; Wiesinger et al., 2025).

Despite the growing body of literature on combined training, relatively limited attention has been given to applied, context-specific mixed training programmes designed for university-level sprinters operating under real training conditions (Loturco et al., 2017; Stellingwerff et al., 2025). In particular, few studies have examined structured mixed-module training implemented during short-term competitive preparation phases, such as university training camps (Girard & Brocherie, 2025; Stellingwerff et al., 2025).

Understanding the effectiveness of such programmes is important for coaches and practitioners working in resource-limited environments who require practical training models capable of simultaneously addressing multiple physical attributes (Haugen et al., 2019; Weldon et al., 2022; Larkin et al., 2022).

The mixed module training programme (MMTP) in the present study was designed to integrate different training components within a structured and progressive framework (Issurin, 2010; Bompa & Buzzichelli, 2018). The programme emphasised balanced exposure to sprint-specific running, strength training, plyometrics, core exercises, and mobility work, with gradual progression across training phases (Cormie et al., 2011; Issurin, 2010; Ramirez-Campillo et al., 2023; Sañudo et al., 2019).

Rather than isolating individual physical qualities, the MMTP was intended to reflect common coaching practice in university-level sprint training, where multiple performance-related attributes must be developed concurrently within limited preparation periods (Haugen et al., 2019; Oliver et al., 2024; Liu et al., 2024).

### Purpose

Therefore, the purpose of the present study was to examine the effects of a 12-week mixed module training programme on selected physical attributes and 100-m sprint performance in university-level sprinters.

### Hypothesis

It was hypothesised that participation in the MMTP would be associated with greater improvements in sprint performance and related physical attributes compared with regular physical activity.

## MATERIALS AND METHODS

### Study Design

The present study employed a quasi-experimental comparative design with pre- and post-intervention measurements. Two groups of university-level sprinters were compared: an experimental group that participated in a mixed module training programme (MMTP) and a control group that continued their regular physical activity.

### Ethical Approval and Consent

The study protocol was reviewed and approved by the Departmental Research Committee of the Department of Physical Education and Sport Science, Visva-Bharati University. All participants were informed about the objectives, procedures, potential risks, and benefits of the study, and written informed consent was obtained prior to participation. All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

### Participants

Twenty-eight (N = 28) male university-level sprinters aged between 20 and 25 years participated in the study. All participants were actively involved in inter-university athletics competitions and had prior experience with structured sprint training. Participants were recruited from Visva-Bharati University, Santiniketan, West Bengal, India.

Baseline demographic and anthropometric characteristics of the participants are presented in Table 1.

**Table 1.** Participants' demographic and anthropometric characteristics

| Variable | EG (N = 18) | CG (N = 10) | t (df = 26) | p |
|---|---|---|---|---|
| Age (Years) | 23.1 ± 1.44 | 23.2 ± 0.98 | -0.24 | 0.812 |
| Height (cm) | 175.0 ± 2.39 | 173.0 ± 5.95 | 0.841 | 0.408 |
| Weight (kg) | 71.3 ± 5.45 | 71.6 ± 4.54 | -0.16 | 0.874 |
| BMI (kg/m²) | 23.4 ± 1.94 | 23.9 ± 2.67 | -0.63 | 0.534 |

Note: EG = Experimental Group; CG = Control Group; cm = centimetres; kg = kilograms; $kg/m^2$ = Weight in kilograms / (Meter × Meter); df = Degree of Freedom; N = Number of Participants.

## Group Allocation

Athletes who were participating in a university training camp in preparation for the All-India Inter-University Athletics Championships were assigned to the experimental group (EG, n = 18). The remaining athletes, who were not part of the training camp during the study period, formed the control group (CG, n = 10). Group allocation was based on logistical and training constraints rather than random assignment.

## Control Group Activity

Participants in the control group continued their regular physical activity throughout the study period. This typically included general sprint drills, running-based conditioning, and routine physical training sessions conducted approximately 3–4 days per week. The control group did not follow a structured or periodized training programme comparable to the MMTP implemented in the experimental group.

### *Mixed Module Training Programme (MMTP)*

MMTP was developed based on established training principles, including progressive overload, variation, and balanced integration of multiple training components. The programme was informed by existing literature on combined and periodized training approaches and was structured to reflect practical coaching conditions at the university level.

The MMTP was implemented over 12 weeks and included sprint-specific running, resistance training, plyometric exercises, core stability training, and mobility work. Training intensity and volume were progressively adjusted across phases to accommodate adaptation and recovery.

A detailed overview of the MMTP is presented in Table 2 and Figure 1.

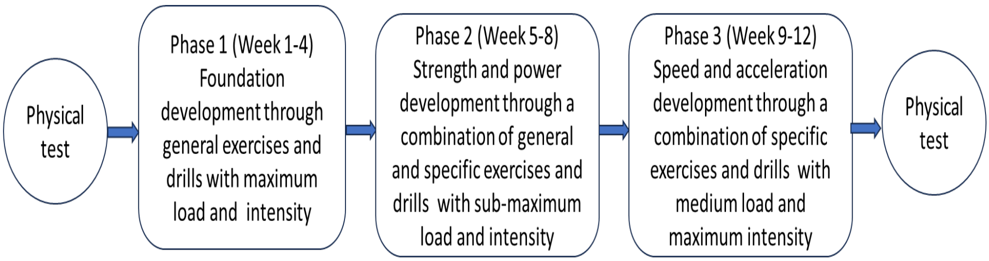


**Fig. 1.** Mixed Module Training Programme (MMTP) across 12 weeks for the EG

**Table 2.** 12 weeks Mixed Module Training Programme (MMTP)

| Phase | Day | Session | Key Exercises/Drills* | Intensity |
|---|---|---|---|---|
| Phase 1 (Weeks 1–4) | 1-4 | AM | 30 min slow CR; Core Circuit (20 reps × 4) | 50% |
| | | PM | 4×300 m, 4×150 m, 4×100 m | 70-80 % |
| | 2-5 | AM | WT (80-85%, 1RM) 10–12 reps × 3 each variation | 50-60 % |
| | | PM | RR [{3× (40, 50, 60, 70 m with Sledge)} ×6] Core Circuit (20 reps × 4) | 70-80 % |
| | 3-6 | AM | 30 min fast CR; Core Circuit (20 reps × 4) | 70% |
| | | PM | SL (400 -200 -100– 200-400) X 3, 5×100 m TR | 65-85 % |
| Phase 2 (Weeks 5–8) | 1-4 | AM | 30 min CR; Core Circuit (20 reps × 4) | 60-70 % |
| | | PM | Same as Phase 1 with increased intensity | 75-90 % |
| | 2-5 | AM | WT (70-75%, 1RM) 12–15 reps × 3 each variation | 70-75 % |
| | | PM | 30 Min Plyometrics; RR {(1×40, 50, 60, 70 m with Sledge) ×6}; Core Circuit (20 reps × 4) | 75-85 % |
| | 3-6 | AM | Fartlek run 30 min; Core Circuit (20 reps × 4) | 75-80 % |
| | | PM | 4×200 m; 8×50 m; 2×100 m; | 70-90 % |
| Phase 3 (Weeks 9–12) | 1-4 | AM | WT (60-65%, 1RM) 15–18 reps × 3 each variation | 80-90 % |
| | | PM | 2×120 m; 3×90 m; 6×60 m, 6×40 m; Core Circuit, (25 reps × 5) | maximal |

| Phase | Day | Session | Key Exercises/Drills* | Intensity |
|---|---|---|---|---|
| | 2-5 | AM | 20 min fast CR; Core Circuit, (25 reps × 5) | 80-90 % |
| | | PM | 40 min Plyometrics; RR [{3× (40, 50, 60, 70 m with Sledge)} ×6]; BC | maximal |
| | 3-6 | AM | WT (60-65%, 1RM) 15–18 reps × 3 each variation | 80-90 % |
| | | PM | acceleration sprints: 6× (30,40,50,60) m, 3× (70,80) m; Core Circuit, (25 reps × 5) | maximal |
| **Rest: Anaerobic activities = 30 sec./1 min; Aerobic activities = 2 – 3 min/5 – 7 min.** | | | | |

Note: Day: 1-4 = Monday & Thursday, 2-3 = Tuesday and Friday. 3-6 = Wednesday & Saturday; AM = Morning; PM = Evening; CR = Continuous Run; Core Circuit = 5 abdominal + 5 back variations; m = Meter; WT = Weight Training (5 upper + 5 lower limbs Alternatively); RM = Repetition Maximum; RR = Resistance Run; SL = Speed Ladder; TR = Tempo Run; Reps = Repetitions; min = minutes; sec. = seconds; Rest = between repetitions/between sets; Anaerobic activities = Sprint, plyometric, strength training, etc.; Aerobic activities = ≥ 150 meters running.

Training sessions were conducted six days per week. Each training day included a morning session (approximately 90 minutes) and an evening session (approximately 120 minutes), incorporating warm-up, main training activities, and cool-down periods. The training schedule was designed to align with the preparation phase for the inter-university competition.

### Outcome Measures and Data Collection Procedures

Pre- and post-intervention assessments were conducted to evaluate sprint performance and selected physical attributes. All tests were performed under standardised field or indoor conditions, following established protocols, and participants completed a standardised warm-up prior to testing.

### 100-m Sprint Test

Sprint performance was assessed using a 100-m sprint test conducted on a standard outdoor track. Participants performed maximal-effort sprints from starting blocks, and sprint time was recorded using manual timing. Two trials were performed, and the best time was used for analysis (Healy et al., 2022).

### Vertical Jump Test (VJT)

Lower-limb explosive power was assessed using the vertical jump test. Participants performed maximal vertical jumps from a semi-squat position, and jump height was calculated as the difference between standing reach and maximal jump reach. Multiple trials were allowed, and the best performance was recorded (Zecirovic et al., 2021).

### Standing Long Jump (SLJ)

Horizontal explosive power was measured using the standing long jump test. Participants performed a two-footed horizontal jump from a standing position, and jump distance was measured from the take-off line to the nearest landing point. The best of three trials was used for analysis (Porter et al., 2010).

### 20-m Sprint Test

Acceleration ability was assessed using a 20-m sprint test performed from a stationary start. Sprint time was manually recorded, and the best performance from the two trials was used for analysis (Kurtoğlu et al., 2024).

### Illinois Agility Test (IAT)

Agility was evaluated using the Illinois Agility Test, conducted according to standardised procedures. Participants completed the test course at maximal speed, and performance time was recorded. The best of the two trials was used for analysis (Salimi & Ferguson-Pell, 2020). A detailed layout of the Illinois Agility Test (IAT) is presented in Figure 2.

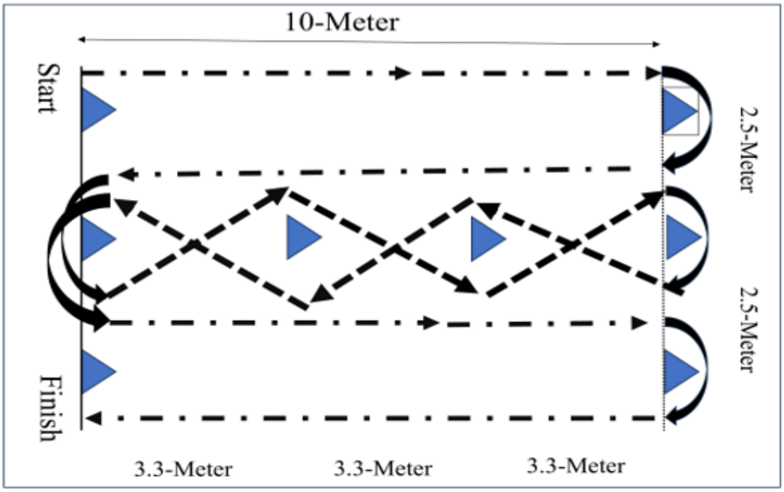


**Fig. 2.** Layout of Illinois Agility Test (IAT)

Manual timing was used for all sprint and agility tests; to reduce measurement variability, multiple timekeepers were employed, and median values were recorded.

### Statistical Analysis

Data were analysed using jamovi statistical software (version 2.7.6). Descriptive statistics are presented as mean ± standard deviation. Baseline differences between groups were assessed using independent-sample t-tests.

Analysis of covariance (ANCOVA) was employed to examine post-intervention group differences while controlling for baseline values. Effect sizes were calculated to estimate the magnitude of between-group differences and were interpreted cautiously due to the sample size. Assumptions of normality and homogeneity of variance were checked prior to inferential analysis. Statistical significance was set at $p < 0.05$.

## RESULTS

All participants in the experimental group completed the training programme, and no training-related injuries were reported.

Descriptive statistics (mean ± SD) for pre- and post-intervention physical performance variables for the experimental group (EG) and control group (CG) are presented in Table 3. The Shapiro–Wilk test indicated that all variables were normally distributed ($p > 0.05$), and Levene's test confirmed homogeneity of variance between groups ($p > 0.05$), supporting the assumptions required for ANCOVA.

**Table 3.** Physical performance characteristics (Mean ± SD) and Shapiro-Wilk of pre- and post-test scores for EG & CG and Levene's Test

| Variables | Test | Mean ± SD | | Shapiro-Wilk p | | Levene's | |
|---|---|---|---|---|---|---|---|
| | | EG (n=18) | CG (n=10) | EG (n=18) | CG (n=10) | F (df=1,26) | p (>0.05) |
| 100-m Sprint (Sec) | Pre | 12.00 ± 0.33 | 12.10 ± 0.38 | 0.50 | 0.98 | 1.18 | 0.29 |
| | Post | 11.80±0.30 | 12.10±0.37 | 0.91 | 0.19 | | |
| VJT (Cm) | Pre | 58.8 ± 1.96 | 60.6 ± 2.25 | 0.30 | 0.19 | 0.14 | 0.71 |
| | Post | 63.9 ± 1.90 | 61.2 ± 2.58 | 0.30 | 0.19 | | |
| SLJ (Cm) | Pre | 240.0 ± 3.42 | 240.0 ± 1.99 | 0.36 | 0.45 | 2.73 | 0.11 |
| | Post | 247.0 ± 4.32 | 241.0 ± 2.24 | 0.47 | 0.63 | | |
| 20-m Sprint (Sec) | Pre | 2.78 ± 0.04 | 2.81 ± 0.02 | 0.28 | 0.57 | 0.44 | 0.51 |
| | Post | 2.69 ± 0.02 | 2.78 ± 0.06 | 0.28 | 0.57 | | |
| IAT(Sec) | Pre | 15.4 ± 0.27 | 15.6 ± 0.34 | 0.69 | 0.83 | 2.52 | 0.12 |
| | Post | 14.8 ± 0.32 | 15.5 ± 0.36 | 0.45 | 0.98 | | |

Note: EG = Experimental Group; CG = Control Group; cm = centimetres; VJT = Vertical Jump Test; SLJ = Standing Long Jump; 20-Meter ST = 20-Meter Sprint Test; IAT = Illinois Agility Test.

After adjusting for baseline values, ANCOVA revealed statistically significant between-group differences in all measured performance variables (Table 4). For the 100-m sprint, a significant group effect was observed ($F(1,25) = 60.55$, $p < 0.01$, $\eta^2p = 0.71$), with the experimental group demonstrating lower adjusted post-test sprint times than the control group.

Significant group effects were also observed for vertical jump ($F(1,25) = 64.87$, $p < 0.01$, $\eta^2p = 0.72$) and standing long jump performance ($F(1,25) = 86.57$, $p < 0.01$, $\eta^2p = 0.78$), with higher adjusted post-test values in the experimental group. Similarly, acceleration (20-m sprint) and agility (Illinois Agility Test) showed significant between-group differences in favour of the experimental group ($p < 0.01$).

Effect sizes indicated substantial between-group differences across all variables (Table 4).

**Table 4.** Analysis of Covariance and Post Hoc Mean Comparison

| Variables | F (1,25) | p | $\eta^2p$ | Adjusted Post Test Mean ± SE | | MD ± SE | t (25) | ptukey | Cohen's d |
|---|---|---|---|---|---|---|---|---|---|
| | | | | EG | CG | | | | |
| 100-m Sprint (Sec) | 60.55 | <0.01* | 0.71 | 11.80 ± 0.018 | 12.04 ± 0.024 | -0.236 ± 0.030 | -7.78 | <0.01* | 3.12 |
| VJT (Cm) | 64.87 | <0.01* | 0.72 | 64.46 ± 0.28 | 60.11 ± 0.39 | 4.351 ± 0.502 | 8.67 | <0.01* | 3.75 |
| SLJ (Cm) | 86.57 | <0.01* | 0.78 | 247.27 ± 0.43 | 241.93 ± 0.57 | 6.340 ± 0.713 | 8.90 | <0.01* | 3.52 |
| 20-m Sprint (Sec) | 40.84 | <0.01* | 0.62 | 2.69 ± 0.008 | 2.78 ± 0.010 | -0.091 ± 0.013 | -6.82 | <0.01* | 2.84 |
| IAT(Sec) | 122.06 | <0.01* | 0.83 | 14.90 ± 0.028 | 15.42 ± 0.038 | -0.525 ± 0.047 | -11.05 | <0.01* | 4.46 |

Note: EG = Experimental Group; CG = Control Group; cm = centimetres; VJT = Vertical Jump Test; SLJ = Standing Long Jump; 20-Meter ST = 20-Meter Sprint Test; IAT = Illinois Agility Test; MD = Mean Difference; * = Significant difference; $\eta^2p$ = Partial eta square.

## DISCUSSION

The purpose of the present study was to examine the effects of a 12-week mixed module training programme (MMTP) on selected physical attributes and 100-m sprint performance in university-level sprinters. The main findings indicate that the experimental group showed significantly greater improvements in sprint performance, explosive power, acceleration, and agility than the control group, which continued regular physical activity. These results suggest that a structured mixed training approach may be effective in enhancing sprint-related performance characteristics in university-level athletes.

### Sprint Performance

The significant improvement observed in 100-m sprint performance in the experimental group may be associated with the structured, progressive organisation of the MMTP (Nicholson et al., 2021; Hicks et al., 2022). The programme combined sprint-specific running with complementary strength, plyometric, and conditioning exercises, reflecting common coaching practice in sprint training (Loturco et al., 2017; Aloui et al., 2021; Oliver et al., 2024). Rather than targeting a single performance component, the MMTP aimed to develop multiple physical attributes concurrently, which may be advantageous in university-level settings where training time and preparation periods are often limited (Issurin, 2010; Cormie et al., 2011; Haugen et al., 2019).

The lack of meaningful improvement in the control group further underscores the potential importance of structured, periodised training exposure. Athletes who continued general physical activity without a systematic training framework did not demonstrate comparable gains in sprint performance over the 12 weeks.

These findings are consistent with previous research showing that structured combined training programmes can improve sprint performance, whereas regular physical activity without systematic organisation may yield little or no improvement (Pavlenko & Pavlenko, 2020; Liu et al., 2025).

### Explosive Power

Improvements in vertical jump and standing long jump performance suggest enhanced lower-limb explosive capacity in the experimental group following the MMTP (Xu et al., 2025; Zhou et al., 2024; Muñoz et al., 2024). The inclusion of resistance training and plyometric exercises across all phases of the programme likely contributed to these improvements by exposing athletes to repeated high-force and high-velocity movements (Zhu et al., 2024; Petrušič, 2024; Mănescu, 2025). Previous research has reported similar benefits of combined strength and plyometric training on jump performance in athletic populations, supporting the present findings (Zhao et al., 2026; Luo et al., 2025; Martín-Moya et al., 2023).

It is important to note that the present study did not aim to isolate the effects of individual training components. Instead, the observed improvements likely reflect the cumulative effect of the integrated training approach employed throughout the intervention period.

### Acceleration and Agility

Acceleration ability, as assessed by the 20-m sprint, and agility performance, measured using the Illinois Agility Test, also showed significant improvements in the experimental group. These attributes are influenced by a combination of sprint mechanics, coordination, and the ability to rapidly generate and apply force during short-duration movements (J. He et al., 2025; Bustamante-Garrido et al., 2023; Singh et al., 2025; Z. He et al., 2025).

The MMTP incorporated sprint drills, resisted runs, and change-of-direction activities, which may have contributed to improved acceleration and agility performance. From an applied perspective, these findings support the use of integrated training models that address multiple movement demands relevant to sprinting rather than relying on isolated training modalities (Aldrich et al., 2024; Sal-de-Rellán et al., 2024; Li et al., 2025; Aboulfaraj et al., 2025).

### Participant Performance Level and Context

Although the absolute sprint times of the participants were lower than those typically reported for elite sprinters, the athletes involved in the present study were representative of university-level competitors within the studied context. At this level, structured and well-organised training programmes may produce noticeable performance improvements, particularly when compared with less systematic training exposure.

Therefore, the results should be interpreted relative to the competitive level and training background of the participants rather than against elite performance benchmarks. The findings remain relevant for university and developmental sport settings where athletes are still progressing toward higher levels of performance.

### Interpretation of the Multi-Component Training Approach

The multi-component nature of the MMTP does not allow attribution of performance improvements to any single training element. Instead, the findings reflect the combined effect of an integrated training approach that balances sprint-specific work with strength, plyometric, and conditioning exercises. This characteristic aligns with real-world coaching practice, where training programmes are rarely limited to a single modality (Haugen et al., 2019; Weldon et al., 2022).

From a practical standpoint, the effectiveness of the MMTP appears to be related to its overall structure, progression, and consistency rather than to isolated training variables.

### Limitations

Several limitations should be acknowledged. The study employed a quasi-experimental design, and group allocation was based on logistical constraints rather than random assignment. The sample size was relatively small, and performance measurements were conducted using manual timing under field conditions, which may introduce measurement variability. Additionally, the integrated nature of the training programme limits the ability to determine the specific contribution of individual training components.

Future research employing larger samples, randomised designs, and advanced measurement tools may help to further clarify the effects and underlying mechanisms of mixed training programmes in sprint athletes.

### Practical Implications

The findings of this study provide practical insights for coaches and practitioners working with university-level sprinters, particularly in environments with limited time and resources. The MMTP offers a structured and adaptable framework that integrates multiple training components within a single programme and may be useful during competitive preparation phases.

Coaches may consider adopting similar mixed training approaches that balance sprint-specific running with strength, plyometric, and conditioning exercises to enhance overall sprint-related performance.

## CONCLUSION

The present study examined the effects of a 12-week mixed module training programme on selected physical attributes and 100-m sprint performance in university-level sprinters. The findings indicate that athletes who participated in the MMTP demonstrated greater improvements in sprint performance, explosive power, acceleration, and agility compared with those who continued regular physical activity.

These results suggest that a structured and progressive mixed training approach can be effective in university-level sprint training contexts, particularly where time, resources, and preparation periods are limited. The integrated nature of the MMTP reflects practical coaching environments and supports the development of multiple performance-related attributes within a single training framework.

Although the study was limited by its quasi-experimental design, small sample size, and field-based measurement procedures, the findings provide useful applied insights for coaches and practitioners working with developmental and university-level sprinters. Future research employing larger samples, randomised designs, and more precise measurement techniques may further clarify the effectiveness and optimisation of mixed training programmes for sprint performance.

## AUTHOR CONTRIBUTIONS

Ashoke Mukherjee and Swarup Mahato contributed to the conception and design of the study. Ashoke Mukherjee conducted data collection and analysis. Both authors contributed to the interpretation of results and the writing and revision of the manuscript. All authors have read and approved the final version of the manuscript.

## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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# Self-compassion as a Protective Mediator Between Childhood Adversity and Stress in Combat Athletes

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**ABSTRACT. Introduction:** Athletes who participate in combat sports commonly experience intense physical and interpersonal stressors. Assessing and regulating stress are essential for performance and well-being in these environments. Although both ACE and self-compassion are independently associated with athletes' psychological functioning, few empirical studies have examined how these factors jointly influence perceived stress in combat sports athletes. **Objective:** This study examined the relationships among adverse childhood experiences (ACEs), self-compassion, and perceived stress in combat sport athletes, and tested whether self-compassion mediates the ACE - stress association. **Method:** In a correlational design, combat athletes (N = 141) completed validated measures of ACEs, self-compassion, and perceived stress. Internal consistency was assessed, correlations were computed, and a multiple regression predicted perceived stress from ACEs and self-compassion. A nonparametric bootstrap mediation (B = 5,000) evaluated the indirect effect ACE → self-compassion → stress. **Results:** Regression showed ACEs ($b = 0.50$, $p = .030$) positively and self-compassion ($b = -0.44$, $p < .001$) negatively predicted stress ($R^2 = .303$). Mediation indicated a significant indirect effect ($a \times b = 0.34$, 95% CI [0.10, 0.64]), consistent with partial mediation. **Conclusion:** Self-compassion was an important predictor and a significant mediator, suggesting self-compassion-based interventions may mitigate stress in combat athletes with ACE histories. Findings align with prior evidence that ACEs elevate stress vulnerability while self-compassion supports adaptive regulation in sport contexts.

***Keywords.*** *adverse childhood experiences, self-compassion, perceived stress, combat sports, athletes.*

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## INTRODUCTION

Combat sports create a unique psychological and physiological context, subjecting athletes to intensities and interpersonal dynamics rarely encountered in other athletic disciplines. Unlike traditional team or individual sports, combat involves structured physical confrontation where the explicit objective, within regulated boundaries, is to cause physical harm to an opponent (James et al., 2018). This environment encompasses a broad spectrum of contact, from controlled recreational sparring to professional full-contact matches that permit high-impact strikes to the head and torso (K-1 Hungary, 2014). For the practitioner, this creates a double pressure system, consisting of a high-intensity physical threat and psychological demand. Crucially, objective physical danger does not unilaterally dictate the athlete's experience; rather, in this field of sport, the interpretation of intent and physical threat makes cognitive assessment more volatile than in non-combative disciplines. The subjective impact of these stressors is strongly mediated by how the individual interprets and regulates their internal state (Slimani et al., 2018). Understanding these dynamics is strategically vital, as the athlete's ability to manage this "interpreted threat" is a primary determinant of both competitive longevity and peak performance. To dissect this regulation, we must evaluate the internal neurobiological mechanisms that govern the stress response.

Analyzing the complexities of elite athlete behavior under pressure requires the synthesis of three specific theoretical pillars: General Adaptation Syndrome (Selye, 1956, 1976), Polyvagal Theory (Porges, 2001, 2007), and Cognitive Appraisal (Lazarus & Folkman, 1984). These frameworks illuminate how an athlete transitions from physiological activation to either peak performance or breakdown. Stress, from an evolutionary perspective, serves to mobilize energy for survival (Bereczkei, 2000). Selye (1956, 1976) defined this as a nonspecific reaction to external demands, distinguishing between *eustress* (the performance-enhancing form of activation) and *distress*. When activation becomes chronic, it results in the maladaptive state described by Sanderson (2018), characterized by elevated cortisol, oxidative stress, and accelerated physiological aging (Aschbacher et al., 2013).

Porges' (2001, 2207) Polyvagal Theory expands this by highlighting the "heart–brain connection" and the critical role of the "Vagus Nerve System" in regulating emotional states. Success in combat depends on autonomic resilience, the ability of the autonomic nervous system to oscillate rapidly between "fight–flight" mobilization and the "social engagement" required for tactical decision-making. The chronic distress and cortisol elevation (General Adaptation Syndrome) identified by Selye (1956, 1976) essentially represent a failure of this autonomic resilience. Finally, biological activation is filtered through cognitive evaluation. Lazarus and Folkman (1984) argue that the distinction between a "threat" and a "challenge" determines success; if an athlete perceives a match as an uncontrollable threat, they suffer heightened tension that disrupts performance. While universal, these biological systems are not static; they are frequently calibrated by an individual's developmental history and "neurobiological sensitization" resulting from early-life experiences.

Adverse Childhood Experiences (ACEs) represent a critical, yet frequently overlooked, variable in the trajectory of sport performance. These early-life adversities, ranging from violence to neglect, fundamentally alter the neurobiological systems responsible for stress regulation, specifically the hypothalamic–pituitary–adrenal (HPA) axis and the amygdala (Felitti et al., 1998). Interpersonal trauma during childhood often creates a maladaptive cognitive architecture, impairing emotional regulation and secure attachment, which manifests in adulthood as complex post-traumatic stress or substance abuse (Bennett, 2022; Peng & Ishak, 2025). Even among highly trained performers, high ACE scores correlate with increased perceived stress and significant psychiatric risks (Brown et al., 2020). Athletic risks of ACE exposure are several: heightened perceived stress and acute reactivity to competitive pressure (Brown et al., 2020), elevated risk of emotion regulation difficulties and problematic substance use (Bennett, 2022; Powless et al., 2025), increased prevalence of depression and suicide attempts compared to athletes with lower ACE scores (Powless et al., 2025).

However, early adversity does not necessitate a path of dysfunction. Many individuals exhibit post-traumatic growth, finding increased strength or purpose through their history (Eger, 2017). Furthermore, sport can serve as a potent vehicle for resilience-building (Norris & Norris, 2021). The variability in these outcomes suggests that specific psychological resources can interrupt the HPA-axis dysregulation caused by ACEs, reshaping the trajectory from trauma toward performance.

Self-compassion has continued to emerge as an important psychological resource in athletic contexts, supporting athletes' emotional resilience and their ability to navigate stressors effectively (Frentz et al., 2025; Magnus et al., 2010; Mosewich, 2020; Mosewich et al., 2011; Mosewich et al., 2013; Semenchuk et al., 2018). Athletes high in self-compassion tend to frame their sport experiences through themes such as balance, growth, and transformation, reflecting its influence on identity development and meaning-making in sport (Frentz et al., 2025). Defined by Neff's (2003, 2023) triad of self-kindness, common humanity, and mindfulness, it provides a trainable, non-pathological alternative to traditional clinical models. A qualitative scoping review by Kullman et al. (2025) highlights that both the "Yin" (gentle) and "Yang" (fierce) expressions of self-compassion are vital. In the "toughness" culture of combat sports, the "Yang" or fierce expression is particularly strategic, providing the protective and motivational qualities necessary to maintain performance without falling into the trap of self-critical rumination

(Eke et al., 2025). The efficacy of self-compassion as a regulatory buffer is well-supported: high self-compassion improves parasympathetic flexibility, leading to better heart rate variability (HRV) reactivity and faster emotional recovery after failure (Ceccarelli et al., 2019; Zhang et al., 2023), athletes with higher levels of self-compassion are more likely to recommit to training goals following a sports injury and display lower fear of failure (Semenchuk et al., 2018; Doorley et al., 2022).

Intervention research consistently demonstrates that self-compassion is trainable. The RESET program significantly increased athletes' self-compassion, reduced self-criticism, rumination, and worrying about setbacks and improved perceived performance relative to control participants (Kuchar et al., 2023; Mosewich et al., 2013). Imagery-based interventions have also been effective; athletes who completed Compassion-Focused Imagery exercises showed improvements in emotion regulation, self-acceptance, and overall psychological well-being (Carson Sackett et al., 2024). By fostering a balanced stance toward internal experiences, self-compassion acts as a mechanism that can mitigate the neurobiological sensitization caused by early trauma, making it an essential focus for the athletic population.

Despite the clear evidence linking ACEs to stress and self-compassion to recovery, a significant research gap exists regarding *combat athletes* (McLoughlin et al., 2020). This population faces unique psychological pressures and a culture of "toughness" that often makes athletes less likely to acknowledge or seek support for mental health challenges (McLoughlin et al., 2020). Self-compassion is therefore a superior strategic intervention because it is a self-administered, non-pathological resource that aligns with the athlete's need for autonomy.

## Goal and Hypotheses

This study models the relationship between adverse childhood experiences and self-compassion as an internal regulatory resource in this specialized group. Based on the synthesis of neurobiological and psychological evidence, we test the following hypotheses:

- **H1:** Adverse Childhood Experiences (ACEs) will be positive predictor of perceived stress, reflecting the long-term impact of early-life neurobiological sensitization, and self-compassion will be negative predictor perceived stress, serving as a robust protective factor against athletic distress.
- **H2:** Self-compassion will act as a significant mediator in the relationship between ACEs and perceived stress, suggesting that developing compassionate regulatory resources can interrupt the maladaptive outcomes typically associated with a history of early-life adversity.

## MATERIALS AND METHODS

### Participants

The sample comprised 141 athletes (112 men, 29 women) aged 18–67 years (M = 34.83, SD = 12.01). Monthly training sessions ranged from 1 to 100 (M = 9.16, SD = 10.06), and years of practice from 1 to 45 (M = 13.05, SD = 11.46).

### Measures

***Perceived Stress*** was assessed using the 10-item Hungarian adaptation of the Perceived Stress Scale (PSS; Cohen et al., 1983; Stauder & Konkolÿ Thege, 2006). The PSS-10 assesses appraised stress over the past month with 10 items (e.g. $4^{th}$ item "In the last month, how often have you felt confident about your ability to handle your personal problems?") rated on a 5-point Likert scale: 0 = *Never*, 1 = *Almost never*, 2 = *Sometimes*, 3 = *Fairly often*, 4 = *Very often*. Items were summed to a total score (0–40) after reversing the reverse-score items (4, 5, 7, 8). The scale is intended for relative comparisons (it is not a diagnostic instrument with official cut-offs). The scale's reliability was good in this sample (α = .87).

***Self-Compassion*** was assessed with the 12-item Hungarian adaptation of the Self-Compassion Scale – Short Form (SCS-SF; Póka et al., 2024; Raes et al., 2011). The SCS-SF measures each of the components of self-compassion (i.e., self-kindness, self-judgment, common humanity, isolation, mindfulness, over-identification) with two items (e.g., "I try to see my failings as part of the human condition"). Items were rated on a 5-point scale (*1 = almost never, 5 = almost always*). The six items that measure the negative dimensions of self-compassion are reverse coded. Scores for self-compassion were calculated by summing the scores ratings on items measuring self-compassionate behaviors (i.e., self-kindness, common humanity, mindfulness) and reverse coded scores on items measuring uncompassionate behaviors towards the self (i.e., self-judgment, isolation, over-identification). The scale had good reliability in this sample (α = .80).

***Adverse Childhood Experiences (ACEs)*** were measured with ACE questionnaire, which is a 10-item yes/no checklist (e.g. "Prior to your 18th birthday, did an adult or person at least 5 years older than you ever touch you in a sexual way, or attempt/actually have oral, anal, or vaginal intercourse with you?") covering exposure to abuse/neglect and household dysfunction before age 18. The ACE score is the sum of "Yes" responses (0–10). Content domains are: emotional, physical, and sexual abuse; emotional and physical neglect; parental separation/divorce; caregiver treated violently; household substance use, mental illness/attempted suicide, and incarceration.

### Research Design and Procedures

This cross-sectional, quantitative, correlational study examined perceived stress and its associations with adverse childhood experiences (ACEs) and self-compassion among combat sport athletes. The study was conducted in accordance with the Code of Ethics of the American Psychological Association. After voluntarily agreeing to participate and providing online consent, participants completed an online structured survey using Google Forms.

To ensure adequate sensitivity, we conducted a priori power analyses using G*Power (v3.1.x) (Faul et al., 2009). For the multiple regression (predicting perceived stress from ACE and self-compassion), assuming a medium effect of $f^2 = .15$, $\alpha = .05$, with two predictors, the required sample size is N = 68 to achieve $1-\beta = .80$ power. Our sample (N = 141) therefore exceeded the a priori requirement. For the mediation (PROCESS Model 4) testing the indirect effect of ACE on stress via self-compassion with bias-corrected bootstrap, the required N depends on the sizes of a and b paths. Using the planning tables from Fritz & MacKinnon (2007), the recommended sample size is $N \approx 116$ for $1-\beta = .80$. Our N = 141 thus provided $1-\beta > .80$ for detecting the indirect effect.

Data were analyzed using IBM SPSS Statistics. Internal consistency of the scales was assessed using Cronbach's alpha coefficients. For interpretation we followed George & Mallery's (2003) recommendations. Descriptive statistics and Pearson correlations were computed for all study variables. Prior to modeling, we inspected assumptions for linear regression (linearity, homoscedasticity, approximate normality of residuals, and collinearity diagnostics). In order to test our first hypothesis, multiple linear regression analysis was conducted, and F statistics with their significance level, $R^2$, and β were reported.

Mediation analyses were also conducted in IBM SPSS Statistics with the PROCESS macro (version 4.0), Model 4, to test a simple mediation in which adverse childhood experiences (ACE; X) predict perceived stress (Y) indirectly via self-compassion (M). We estimated the total effect (c), the a-path ($X \rightarrow M$), the b-path ($M \rightarrow Y \mid X$), and the direct effect ($c'$; $X \rightarrow Y \mid M$) following standard SPSS/PROCESS procedures. The indirect effect ($a \times b$) was estimated via non-parametric bootstrap (B = 5,000) with bias-corrected 95% confidence intervals; mediation was concluded when the interval did not include zero, consistent with PROCESS guidance. All coefficients are reported as unstandardized b (primary) with SE, *t*, *p*, and 95% CIs, and standardized β (for comparability). Effects were considered significant at level $\alpha = .05$.

## RESULTS

### Descriptive Statistics and Correlations

Descriptive statistics and correlations between main variables are presented in Table 1.

**Table 1.** Descriptive statistics and correlations between investigated variables (N = 141)

| Variable | Min. | Max. | M | SD | 1. | 2. | 3. |
|---|---|---|---|---|---|---|---|
| 1. Perceived Stress | 0 | 34 | 14.81 | 7.02 | - | | |
| 2. Self-Compassion | 18 | 54 | 39.17 | 7.96 | -.53** | - | |
| 3. ACE | 0 | 8 | 2.59 | 2.24 | .27** | -.22** | - |

Notes: PSS-10 = Perceived Stress; SCS-SF = Self-Compassion; ACE = Adverse Childhood Experiences. $p < .01$ (**), $p < .05$ (*)

Perceived stress scores averaged 14.81 (SD = 7.02), self-compassion averaged 39.17 (SD = 7.96), and ACE scores averaged 2.59 (SD = 2.24). Pearson correlations revealed that perceived stress was positively associated with ACE ($r = .27$, $p = .001$) and negatively associated with self-compassion ($r = -.53$, $p < .001$). ACE was also negatively correlated with self-compassion ($r = -.22$, $p = .01$).

### Regression Analysis

To test the first hypothesis, a multiple regression analysis was conducted, in order to predict perceived stress from ACE and self-compassion. The model was significant, $F(2, 138) = 30.02$, $p < .001$, explaining 30.3% of the variance ($R^2 = .303$, adjusted $R^2 = .293$, N = 141). ACE was a positive predictor (b = 0.50, SE = 0.23, $p = .030$), and self-compassion was a negative predictor (b = −0.44, SE = 0.06, $p < .001$). Standardized coefficients indicated that self-compassion ($\beta = -.49$) had a stronger effect than ACE ($\beta = .16$). The results of regression analyses are presented in Table 2. Based on these results, our first hypothesis was confirmed.

**Table 2.** Multiple Regression Predicting Perceived Stress from ACE and Self-Compassion (N = 141)

| Outcome: perceived stress | b | *SE* | *t*(138) | *p* | β |
|---|---|---|---|---|---|
| Self-compassion | -.44 | .06 | -6.77 | <.01 | -.49 |
| ACE | .50 | .23 | 2.20 | .03 | .16 |

Note. Unstandardized coefficients (b) with standard errors (SE), the significance level (*p*) and standardized coefficients (β) are shown.
Dependent variable: Perceived Stress (PSS-10 total).
Predictors entered simultaneously: ACE total and Self-Compassion (SCS-SF total).
Assumption checks (linearity, homoscedasticity, approximate normality of residuals, and collinearity) were satisfactory.

## Mediation Analysis

A mediation model was tested to examine our second hypothesis, whether self-compassion mediates the association between adverse childhood experiences (ACEs) and perceived stress among elite combat sport athletes. A non-parametric bootstrap mediation analysis (B = 5,000; bias-corrected 95% CI) indicated that self-compassion partially mediated the association between adverse childhood experiences (ACEs) and perceived stress.

The total effect of ACE on stress was significant (c = 0.84, *SE* = 0.19, *t*(139) = 4.42, *p* < .001), and this effect remained significant but was reduced when the mediator was included (c′ = 0.50, *SE* = 0.23, *t*(138) = 2.18, *p* = .031). ACEs significantly predicted lower self-compassion (a = –0.23, *SE* = 0.09, *t*(139) = −2.53, *p* = .013), and self-compassion significantly predicted lower perceived stress when controlling for ACEs (b = –0.44, *SE* = 0.06, *t*(138) = −6.84, *p* < .001).

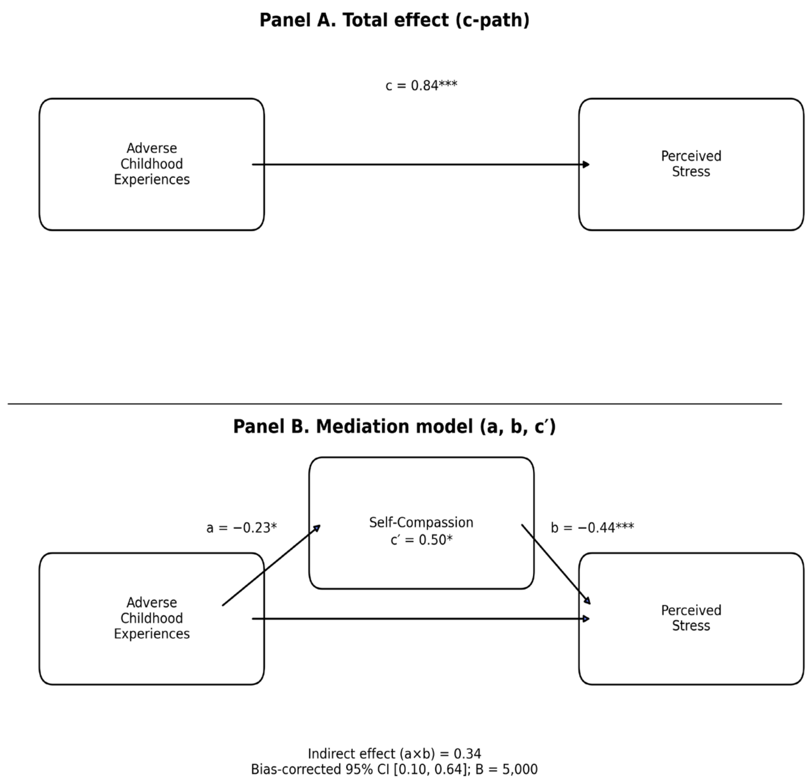


**Fig. 1.** Two-panel mediation diagram for the association between adverse childhood experiences (ACE) and perceived stress in elite combat athletes.

Notes. Unstandardized coefficients (**b**) are displayed on arrows; asterisks mark significance (p < .05, *p < .01, **p < .001). Sample size: **N = 141**.

The indirect effect (a × b = 0.34) was significant, as the 95% confidence interval did not include zero [0.10, 0.64], indicating partial mediation. These results (also, presented in Table 3 and Figure 1) demonstrate that self-compassion is a psychological mechanism, a protective mediator between adverse childhood experiences and perceived stress among combat sport athletes.

**Table 3.** Results of mediation analysis (N = 141)

| **Path** | **Effect (b)** | ***SE*** | ***t*(df)** | ***p*** | **95% CI** | **β** | **Interpretation** |
|---|---|---|---|---|---|---|---|
| a: ACE à SC | -0.23 | 0.09 | -2.53 (139) | .013 | [−0.41, −0.05] | -.22 | ACE predicts lower SC |
| b: SC à Stress (ACE-controlled) | -0.44 | 0.06 | -6.84 (138) | <.001 | [−0.56, −0.32] | -.49 | SC predicts lower stress |
| c: ACE à Stress (total) | 0.84 | 0.19 | 4.42 (139) | <.001 | [0.47, 1.21] | .27 | ACE predicts higher stress |
| c': ACE à Stress (direct; SC-controlled) | 0.50 | 0.23 | 2.18 (138) | .031 | [0.05, 0.96] | .16 | Reduced effect but significant |
| Indirect (a x b) | 0.34 | - | - | | [.10, .64] | .11 | Significant mediation |

Notes: SC – Self-Compassion; ACE – Adverse Childhood Experience

## DISCUSSION

### General Discussion

The present study examined the relationships among adverse childhood experiences (ACEs), self-compassion, and perceived stress in combat sport athletes. Consistent with prior research on trauma and stress regulation (Felitti et al., 1998; Brown et al., 2020), ACEs were positive predictors for perceived stress, highlighting the enduring impact of early adversity on stress vulnerability in high-pressure environments.

Self-compassion emerged as a robust protective factor, demonstrating both a strong direct effect on perceived stress and a significant mediating role in the ACE–stress link. These findings align with previous evidence that self-compassion fosters adaptive coping, reduces rumination, and enhances emotional recovery in athletes (Ceccarelli et al., 2019; Doorley et al., 2022; Kuchar et al., 2023). The negative correlation between ACE and self-compassion suggests that early adversity may undermine the development of self-kindness and emotional balance, thereby increasing susceptibility to stress.

The mediation results underscore the potential of self-compassion as a mechanism through which the negative effects of ACEs on stress can be mitigated. While ACEs exerted a residual direct effect, indicating that other pathways (e.g., neurobiological sensitivity, emotion regulation deficits) may also contribute, the indirect effect via self-compassion was substantial. This supports the integration of compassion-based interventions in athlete mental health programs, particularly for those with trauma histories.

### Limitations and Future Directions

The cross-sectional design precludes causal inference, and self-report measures may be subject to recall bias. Future research should employ longitudinal or experimental designs to confirm the mediating role of self-compassion and explore additional moderators (e.g., fear of self-compassion, coping styles). Examining physiological stress markers (e.g., cortisol, HRV) alongside psychological variables would provide a more comprehensive understanding of stress regulation in combat athletes.

## CONCLUSIONS

Combat sports impose unique stress demands due to their inherently aggressive and high-risk nature (James et al., 2018; Slimani et al., 2018). In our study, self-compassion emerged as a robust protective factor, demonstrating both a strong direct effect on perceived stress and a significant mediating role in the ACE–stress link. Based on these results, enhancing self-compassion in this population is crucial, may not only buffer stress but also promote resilience and performance stability under pressure. Brief interventions such as mindfulness-based self-compassion training have shown promise in collegiate athletes (Kuchar et al., 2023) and could be adapted for combat sport contexts.

**CONFLICT OF INTEREST**
The authors declare no conflict of interest.

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# Influence of Resistance Training Volume on Muscular Fitness and Strength Development in University Students

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**ABSTRACT. Introduction.** Muscular fitness is essential for health and performance in young adults. Training volume plays a key role in resistance training adaptations, yet limited research compares different volumes in university students. **Objective.** This study examined the influence of resistance training volume on muscular fitness and strength development in students aged 20 to 26 years. **Methods.** Thirty two university students were assigned to a moderate volume group or a high volume group. Both groups trained three times per week for eight weeks at 65 to 80 percent of one repetition maximum. The moderate group performed three sets per exercise, while the high volume group performed five sets. Maximal strength was assessed using bench press and squat one repetition maximum tests. Muscular endurance was evaluated through push up and sit up tests. Paired and independent samples t tests were applied. **Results.** Both groups showed significant improvements in all variables after training, with p values lower than .001. The high volume group demonstrated greater mean increases across all measures. A significant between group difference was observed in the sit up test, favoring the high volume protocol. **Conclusions.** Resistance training significantly improves muscular fitness in university students. Both volumes are effective, while higher volume produces greater improvements, especially in muscular endurance.

***Keywords***: *resistance training, training volume, muscular fitness, maximal strength, muscular endurance, university students*

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## INTRODUCTION

Muscular fitness represents a central component of physical performance and long term health in young adults. It includes maximal strength and muscular endurance, both of which influence posture, movement efficiency, injury prevention, and metabolic regulation (American College of Sports Medicine, 2009). During university years, academic demands often increase sedentary behavior, which may negatively affect physical condition. Structured resistance training offers an effective strategy to counteract this decline and improve functional capacity (Keating et al., 2015).

Resistance training produces adaptations at neural and muscular levels. Early strength gains occur primarily through improved motor unit recruitment, synchronization, and firing frequency (Moritani & deVries, 1979). With continued exposure to progressive overload, structural adaptations such as muscle fiber hypertrophy and increases in cross sectional area contribute to further improvements (Schoenfeld, 2010). These mechanisms explain the consistent increases in maximal strength observed in young adults following structured programs.

Maximal strength, commonly assessed through the one repetition maximum test, represents a reliable indicator of neuromuscular performance (Kraemer & Ratamess, 2004). Muscular endurance reflects the capacity to sustain repeated contractions against submaximal resistance and is strongly linked to daily functional tasks and sport specific performance (Campos et al., 2002). Enhancing both components improves overall muscular fitness and supports long term physical development.

Among resistance training variables, volume plays a decisive role in adaptation. Training volume is usually quantified through total sets and repetitions performed at a given intensity. Research indicates that weekly set volume significantly influences hypertrophy and strength outcomes (Schoenfeld, Ogborn, & Krieger, 2017). Meta analytic evidence supports a dose response relationship between higher training volumes and greater muscle mass increases, especially in young adults (Schoenfeld et al., 2019). However, the extent to which volume influences maximal strength in short term interventions remains debated (Grgic et al., 2018). In university populations, optimizing training volume has practical implications. Students often manage academic workload, limited recovery time, and varying levels of training experience. Identifying whether moderate volumes produce similar adaptations compared to higher volumes allows practitioners to design efficient programs. If higher volumes lead to superior endurance or hypertrophy gains, program prescription can prioritize increased set numbers when recovery capacity permits.

Previous investigations conducted in youth and student populations highlight the importance of structured training models in improving physical performance. For example, Teris, Lakotos, and Koronas (2024) demonstrated that well designed training interventions significantly enhance technical and physical capacities in junior athletes. Although focused on skill development, the findings emphasize that systematic program design leads to measurable improvements. Similarly, Onea and Balint (2017) reported associations between physical fitness levels and injury incidence, reinforcing the importance of muscular conditioning in youth populations. Neuromuscular efficiency and biomechanical adaptations also play a critical role in performance development. Onea, Balint, and Pascu (2017) described how targeted training influences lower limb neuromuscular patterns and biomechanical efficiency in hurdling events. These findings support the concept that structured resistance training can modify neuromuscular characteristics that underlie strength expression.

Beyond performance enhancement, resistance training contributes to physiological regulation. Badau et al. (2019) demonstrated that physiological parameters in athlete students are influenced by body composition and hydration status. Improved muscular fitness may positively affect cardiovascular and metabolic markers, strengthening the argument for systematic resistance training in university settings. Ethical and professional standards must also guide training implementation in academic institutions. Teris and Enoiu (2023) highlighted the importance of ethical norms within military academic physical education environments. Teris and Alecu (2025) further emphasized adherence to ethical and deontological principles in university physical education activities. These studies underline that resistance training interventions in academic settings must combine scientific rigor with professional responsibility.

While previous research has explored training effects in athletes and youth, fewer controlled studies have directly compared moderate and high resistance training volumes in general university students aged 20 to 26 years. Young adults possess high adaptive potential due to favorable hormonal profiles and neuromuscular plasticity (Peterson et al., 2004). Even moderate programs can induce substantial improvements in strength and endurance (ACSM, 2009). However, clarifying whether higher volumes produce superior outcomes remains relevant for evidence based prescription.

Therefore, the aim of this study was to examine the influence of resistance training volume on muscular fitness and strength development in university students aged 20 to 26 years. The intervention compared moderate and high volume protocols over eight weeks. Maximal strength was assessed through one repetition maximum tests, and muscular endurance was evaluated through standardized field tests. It was hypothesized that both protocols would significantly improve muscular fitness, with higher training volume producing greater improvements, particularly in endurance related outcomes.

## MATERIAL AND METHODS

The purpose of this study was to examine the influence of resistance training volume on muscular fitness and strength development in university students aged 20 to 26. The intervention lasted eight weeks and followed a pre test and post test experimental design, with assessments conducted before and after the training period.

### Participants

Thirty two university students participated in the study. Their age ranged between 20 and 26 years, with a mean age of 22.8 years. All participants were enrolled in undergraduate programs and volunteered to take part in a structured resistance training program. Inclusion criteria were age between 20 and 26 years, apparently healthy status, absence of musculoskeletal injuries in the previous six months, and no participation in systematic resistance training during the last three months. Exclusion criteria included absence from more than three training sessions, incomplete testing data, or withdrawal from the study.

All participants provided written informed consent prior to enrollment. The study was conducted in accordance with institutional ethical standards for research involving human subjects.

### Study Design

The study followed a pre test and post test design over eight weeks. All participants completed muscular fitness assessments before the intervention and immediately after the training period. The research design compared two resistance training volumes within a structured program. Participants were assigned to one of two training groups based on total sets performed per exercise. One group followed a moderate volume protocol, while the other followed a high volume protocol.

### Training Protocol

Training sessions, presented in table 1, were performed three times per week on non consecutive days. Each session lasted approximately 60 minutes and was supervised by certified strength and conditioning specialists to ensure correct execution and compliance. The training program included multi joint and single joint exercises targeting major muscle groups. The exercises were barbell squat, bench press, lat pulldown, Romanian deadlift, shoulder press, leg press, biceps curl, and triceps extension. Training intensity ranged between 65 and 80 percent of one repetition maximum. Load progression was applied every two weeks according to individual performance improvements. The moderate volume group performed three sets per exercise. The high volume group performed five sets per exercise. Rest intervals were standardized between 90 and 120 seconds between sets.

**Table 1**. Resistance Training Protocol Over 8 Weeks

| **Exercise** | **Intensity (%1RM)** | **Moderate Volume Group** | **High Volume Group** | **Rest Interval** |
|---|---|---|---|---|
| Barbell Squat | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Bench Press | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Lat Pulldown | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Romanian Deadlift | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Shoulder Press | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Leg Press | 65 to 80 | 3 sets × 8 to 12 reps | 5 sets × 8 to 12 reps | 90 to 120 s |
| Biceps Curl | 65 to 75 | 3 sets × 10 to 12 reps | 5 sets × 10 to 12 reps | 60 to 90 s |
| Triceps Extension | 65 to 75 | 3 sets × 10 to 12 reps | 5 sets × 10 to 12 reps | 60 to 90 s |

* %1RM - percentage of your one repetition maximum.
** Training frequency was three sessions per week on non consecutive days. Load progression was applied every two weeks based on individual performance capacity. All sessions were supervised to ensure correct technique and adherence to the prescribed intensity and volume.

### Fitness Assessments and Measurements

Muscular strength and muscular endurance were evaluated using standardized field tests.

Maximal strength was assessed and presented in Table 2, through the one repetition maximum test for bench press and squat. A standardized warm up protocol was applied before testing. The highest successfully lifted load with correct technique was recorded. Upper body muscular endurance was evaluated using the push up test. Participants performed the maximum number of repetitions until failure. Abdominal muscular endurance was measured using the sit up test. The maximum number of repetitions completed in 60 seconds was recorded. All assessments were conducted indoors under controlled conditions. The same evaluators supervised both pre test and post test sessions to ensure consistency.

**Table 2**. Muscular Fitness Assessment Protocol

| Test | Variable Measured | Protocol Description | Outcome Recorded |
|---|---|---|---|
| Bench Press 1RM | Maximal upper body strength | Progressive loading until one repetition maximum with correct technique | Maximum load in kg |
| Squat 1RM | Maximal lower body strength | Progressive loading until one repetition maximum with correct technique | Maximum load in kg |
| Push Up Test | Upper body muscular endurance | Maximum repetitions performed continuously until failure | Number of repetitions |
| Sit Up Test | Abdominal muscular endurance | Maximum repetitions completed in 60 seconds | Number of repetitions |

* 1RM – one repetition maximum
** All tests were performed indoors under standardized conditions. A general warm up of 10 minutes was completed before strength testing. The same evaluators supervised both pre test and post test sessions to ensure consistency and reliability of measurements.

### Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional ethics committee. Written informed consent was obtained from all participants and their legal guardians. Participants were informed of their right to withdraw at any time without penalty.

### Statistical Analysis

Descriptive statistics included mean, standard deviation, minimum, and maximum values for each variable. Paired samples t tests were used to examine within group differences between pre test and post test results. Independent samples t tests were applied to compare post intervention results between the moderate and high volume groups. Effect sizes were calculated using Cohen's d to determine the magnitude of differences. Statistical significance was set at p lower than .05. Data were analyzed using IBM SPSS version 26.

## RESULTS

The results of the eight week resistance training intervention are presented below. Analyses include descriptive statistics for the total sample, within group comparisons for moderate and high volume groups, and post test comparisons between groups.

Table 3 presents the descriptive statistics for all muscular fitness variables at initial test and final test for the total sample of 32 subjects. All variables increased from pre to post intervention.

**Table 3.** Descriptive statistics for all tests

| Test | Phase | Min | Max | X | SD |
|---|---|---|---|---|---|
| Bench Press 1RM (kg) | IT | 35.0 | 86.5 | 61.64 | 11.03 |
| | FT | 45.0 | 91.5 | 69.27 | 11.20 |
| Squat 1RM (kg) | IT | 53.0 | 120.0 | 86.38 | 14.39 |
| | FT | 67.5 | 137.0 | 99.13 | 15.75 |
| Push Up Test (reps) | IT | 10 | 35 | 22.47 | 6.49 |
| | FT | 12 | 44 | 28.81 | 7.21 |
| Sit Up Test (reps, 60 s) | IT | 15 | 49 | 28.72 | 6.83 |
| | FT | 19 | 53 | 36.28 | 7.78 |

Note. IT = initial test, FT = final test, Min = minimum value, Max = maximum value, X = arithmetic mean, SD = standard deviation, 1RM = one repetition maximum, kg = kilograms, reps = repetitions, s = seconds.

Bench press 1RM increased by approximately 7.6 kg on average. Squat 1RM increased by nearly 13 kg. Push up performance improved by more than 6 repetitions, while sit up performance increased by over 7 repetitions. These results indicate a clear positive adaptation to resistance training in the total sample.

### Within Group Comparisons

Table 4 presents inferential statistics for the moderate volume group of 16 subjects. All variables improved significantly from pre to post intervention.

**Table 4.** Inferential statistics for the Moderate volume group

| Test | DX (FT - IT) | DSD | 95% CI low | 95% CI high | p | d |
|---|---|---|---|---|---|---|
| Bench Press 1RM (kg) | 5.44 | 1.85 | 4.45 | 6.42 | < 0.001 | 2.94 |
| Squat 1RM (kg) | 8.66 | 2.25 | 7.46 | 9.86 | < 0.001 | 3.85 |
| Push Up Test (reps) | 4.19 | 2.12 | 3.06 | 5.31 | < 0.001 | 1.98 |
| Sit Up Test (reps, 60 s) | 5.81 | 2.07 | 4.71 | 6.92 | < 0.001 | 2.81 |

Note. DX = mean difference between final test and initial test, DSD = standard deviation of differences, CI = confidence interval, p = paired samples t test significance level, d = Cohen's d effect size, 1RM = one repetition maximum, kg = kilograms, reps = repetitions.

The moderate volume protocol led to significant improvements in maximal strength and muscular endurance. Effect sizes were large across all variables, especially for squat 1RM.

**Table 5.** Inferential statistics for the High volume group

| Test | DX (FT - IT) | DSD | 95% CI low | 95% CI high | p | d |
|---|---|---|---|---|---|---|
| **Bench Press 1RM (kg)** | 9.81 | 2.19 | 8.64 | 10.98 | < 0.001 | 4.48 |
| **Squat 1RM (kg)** | 17.91 | 3.00 | 16.31 | 19.51 | < 0.001 | 5.97 |
| **Push Up Test (reps)** | 8.50 | 2.80 | 7.01 | 9.99 | < 0.001 | 3.03 |
| **Sit Up Test (reps, 60 s)** | 9.31 | 2.22 | 8.13 | 10.50 | < 0.001 | 4.20 |

Note. DX = mean difference between final test and initial test, DSD = standard deviation of differences, CI = confidence interval, p = paired samples t test significance level, d = Cohen's d effect size, 1RM = one repetition maximum, kg = kilograms, reps = repetitions.

The high volume protocol presented in Table 5 produced larger mean improvements in all variables compared to the moderate volume group. Squat 1RM increased by nearly 18 kg, and bench press by almost 10 kg. Muscular endurance improvements were also greater, with increases of over 8 repetitions in both push up and sit up tests. Effect sizes were very large, particularly for lower body strength.

## Between Group Comparisons

**Table 6.** Post Test Independent t Tests, Moderate vs High Volume

| Test | X Moderate | SD Moderate | X High | SD High | p | d |
|---|---|---|---|---|---|---|
| Bench Press 1RM (kg) | 66.94 | 10.41 | 71.59 | 11.81 | 0.246 | 0.42 |
| Squat 1RM (kg) | 94.22 | 11.69 | 104.03 | 18.02 | 0.079 | 0.65 |
| Push Up Test (reps) | 26.50 | 6.59 | 31.13 | 7.25 | 0.069 | 0.67 |
| Sit Up Test (reps, 60 s) | 32.75 | 7.99 | 39.81 | 5.90 | 0.008 | 1.01 |

Note. X Moderate = post test mean value for moderate volume group, X High = post test mean value for high volume group, SD = standard deviation, p = independent samples t test significance level, d = Cohen's d effect size, 1RM = one repetition maximum, kg = kilograms, reps = repetitions.

At post test, presented in Table 6, the high volume group showed higher mean values in all variables. However, statistically significant differences were observed only for the sit up test. The effect size for this variable was large, indicating a meaningful advantage of higher training volume for abdominal muscular endurance. For squat and push up performance, p values approached statistical significance and effect sizes were moderate to large. This suggests a tendency toward greater adaptations with higher volume, although differences did not reach the conventional threshold for significance in maximal strength measures.

Overall, both training volumes significantly improved muscular fitness. Higher training volume produced greater magnitudes of change, with clear superiority in abdominal muscular endurance and consistent trends in maximal strength and upper body endurance.

## DISCUSSIONS

The purpose of this study was to examine the influence of resistance training volume on muscular fitness and strength development in university students aged 20 to 26. The results show that both moderate and high volume resistance training programs significantly improved maximal strength and muscular endurance after eight weeks. The high volume protocol produced greater mean improvements across all variables, with statistically significant superiority in abdominal muscular endurance.

The significant increases in bench press and squat 1RM in both groups confirm that structured resistance training is effective in improving maximal strength in young adults. These findings align with previous research demonstrating that progressive overload induces neural adaptations and increases in muscle cross sectional area, which directly contribute to strength gains (Kraemer & Ratamess, 2004; Schoenfeld, 2010). The magnitude of improvement observed in this study, especially in the high volume group, is consistent with reports that untrained or recreationally trained individuals experience substantial early strength gains during the first two to three months of structured training (Peterson et al., 2004).

The greater improvements observed in the high volume group support the concept that training volume is a key driver of muscular adaptation. Volume represents the total amount of work performed and directly influences mechanical tension and metabolic stress, two major stimuli for hypertrophy and strength development (Schoenfeld, Ogborn, & Krieger, 2017). In the present study, the high volume group demonstrated nearly double the improvement in squat 1RM compared to the moderate volume group. Although between group differences in maximal strength did not reach statistical significance, the effect sizes indicate a meaningful practical difference.

Previous meta analyses have shown a dose response relationship between training volume and hypertrophy, suggesting that higher weekly set numbers produce greater muscle growth, particularly in young adults (Schoenfeld et al., 2019). The current findings partially support this perspective. While maximal strength differences between groups were not statistically significant, the consistent trend toward greater improvements with higher volume suggests that volume may influence the magnitude of adaptation, especially over longer interventions.

The most pronounced between group difference was observed in the sit up test, where the high volume group showed significantly greater improvements. This finding indicates that muscular endurance may be more sensitive to increases in training volume than maximal strength. Muscular endurance improvements depend on metabolic adaptations, capillary density, and fatigue resistance, which respond favorably to greater training workloads (Campos et al., 2002). The higher number of sets performed by the high volume group likely increased time under tension and metabolic accumulation, contributing to superior endurance gains.

The improvements in push up performance further support the role of volume in enhancing muscular endurance. Although post test differences did not reach statistical significance, the moderate to large effect size suggests a practical advantage for higher training volume. Similar findings have been reported in studies comparing different resistance training volumes, where higher set protocols resulted in greater endurance related adaptations (Rhea et al., 2003).

It is important to consider that both groups showed statistically significant improvements in all measured variables. This highlights that even moderate training volumes are sufficient to elicit meaningful gains in muscular fitness among university students. Young adults typically demonstrate high responsiveness to resistance training due to favorable hormonal profiles and adaptive capacity (ACSM, 2009). Therefore, moderate volume training remains a viable strategy when time efficiency or recovery capacity is limited.

The absence of statistically significant between group differences in maximal strength may be explained by several factors. First, the sample size was relatively small, which reduces statistical power. Second, the intervention duration was eight weeks, a period during which neural adaptations dominate strength gains (Moritani & deVries, 1979). Neural improvements may occur similarly across different volume conditions when intensity is comparable. A longer intervention may reveal clearer structural differences related to hypertrophy.

These findings are consistent with evidence suggesting that both moderate and high volume resistance training can improve strength when intensity is appropriately prescribed (Grgic et al., 2018). The key factor appears to be progressive overload rather than volume alone. However, when the objective is to maximize hypertrophy and muscular endurance, increasing weekly set volume may provide additional benefits (Schoenfeld et al., 2017).

From a practical perspective, the results suggest that university students seeking improvements in general muscular fitness can achieve significant benefits with structured resistance training performed three times per week. If the goal is to maximize muscular endurance, especially in the abdominal region, a higher volume protocol may offer superior outcomes. Coaches and practitioners should balance volume with recovery capacity, academic workload, and individual tolerance.

Overall, this study reinforces the importance of structured resistance training in young adults and highlights the role of training volume as a relevant variable in program design. Future research should examine longer interventions, include larger samples, and directly assess muscle hypertrophy through imaging techniques to clarify the relationship between volume, strength, and structural adaptations.

## CONCLUSIONS

The study examined the influence of resistance training volume on muscular fitness and strength development in university students aged 20 to 26 years. After eight weeks of structured training, both moderate and high volume protocols produced significant improvements in maximal strength and muscular endurance.

Bench press and squat one repetition maximum values increased significantly in both groups. Push up and sit up performance also improved in all participants. These findings confirm that structured resistance training performed three times per week is sufficient to enhance muscular fitness in young adults.

The high volume protocol produced greater mean improvements across all variables. A statistically significant advantage was observed in abdominal muscular endurance, where the high volume group demonstrated superior post test results. For maximal strength and upper body endurance, higher volume generated larger effect sizes and greater magnitude of change, although differences did not reach statistical significance.

These results suggest that moderate training volumes are effective for improving general muscular fitness in university students. When the objective is to maximize muscular endurance, increasing weekly training volume may provide additional benefits. Program design should balance training volume with recovery capacity, academic workload, and individual tolerance.

**CONFLICT OF INTEREST**

The author declare no conflict of interest.

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# Evaluating the Behavior of Football Coaches in the U15 Category Through the Eyes of Players – An Intercultural Approach

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**ABSTRACT.** Leadership in sport, especially at the children's and junior levels, involves a complex process of influencing attitudes, emotions, and relationships within a team. This study aims to investigate differences in perception between coaches and players from different countries to determine the extent to which cultural and national environments influence perceptions of coaches' leadership behavior. We used the Multidimensional Scale of Leadership in Sport (MSLS) to compare players' perceptions of their coach's behavior before and after competition, to find differences determined by competitive experience and cultural context. 82 players and 4 head coaches participated. The data were analyzed using the Kruskal-Wallis test, followed by Dunn-Bonferroni post-hoc tests. The results highlighted significant intercultural differences across nine dimensions of leadership: vision, inspiration, instruction, individualization, support, positive and negative feedback, active management, and passive management. Coaches in Romania and Ireland were evaluated more positively regarding supportive and transformational behaviors, while the Montenegro coach exhibited a more authoritarian style. The conclusions suggest that cultural values influence how young athletes perceive their coaches' leadership behaviors, highlighting the importance of critical reflection and cultural adaptability in football.

***Keywords***: *coach-athlete relationship, behavior, leadership, intercultural comparison, youth football*

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## INTRODUCTION

Coaches' behavior has a big impact on athletes' psychological, motivational, and social development, significantly influencing the individual and collective performance of the team (Jowett & Cockerill, 2003; Laborde et al., 2016). Leadership in sport, especially at the children's and junior levels, involves a complex process of influencing attitudes, emotions, and relationships within a team. At the youth level, the coach's job is not limited to making tactical decisions but involves a great deal of pedagogical knowledge that contributes to the development of players who are confident in their own abilities, resilient, and competitive.

The leadership styles adopted by coaches—whether transactional, authoritarian, or transformational—can shape group dynamics, athlete motivation, and the psychosocial climate of training (Chelladurai & Saleh, 1980; Charbonneau et al., 2001).

Numerous studies have shown that transformational leadership, characterised by intellectual stimulation and consideration of the individual, is associated with greater team cohesion, satisfaction, and collective efficacy (Bass & Riggio, 2006; Gomes et al., 2019). In contrast, while transactional or authoritarian leadership styles can be effective in the short term, they can lead to controlled motivation and less empathetic relationships between coaches and athletes (Horn, 1985; Mallet, 2010). In this context, understanding the relationship between coach and athlete is important for interpreting the coach's behaviour and how it is perceived by the players (Jowett, 2024; Zhao & Jowett, 2023).

Recent literature highlights the importance of a dual perspective on coach behavior, both from the coach's and the athletes' point of view, to highlight possible discrepancies between coaches' intentions and the perceptions of those being coached (McGuckin et al., 2022). For example, athletes' evaluations of coaches' behavior differ depending on their perception of their performance and the degree to which they achieve their goals (Gomes et al., 2019) Football players who perceived better athletic performance and the achievement of team goals evaluated coaches' behavior more positively at the end of the season compared to the beginning. This change in perception suggests that athletes' perceptions may evolve throughout their relationship with the coach, being influenced by context and accumulated experiences.

This study aims to investigate differences in perception between coaches and players from different countries in order to determine the extent to which cultural and national environments influence perceptions of coaches' leadership behavior. The study used the Multidimensional Scale of Leadership in Sport, which was completed by both players and coaches from four Under-15 national teams: Romania, Greece, Montenegro, and Ireland.

Through this approach, the present study aims to make an original contribution to understanding the mechanisms by which coaches' behavior is perceived and interpreted differently by athletes and coaches, with the aim of discovering new practical directions for optimizing the coach-athlete relationship and the motivational climate in youth sports.

The first objective of this study was to compare players' perceptions of coaches' leadership behavior before and after competition, while the second was to explore possible variations in the perception of leadership behavior depending on the country of origin of the coaches and players who participated in this study.

### Hypotheses

We believe that the scores obtained by players on the questionnaire regarding coaches' leadership behavior will show statistically significant differences between the two assessment moments: before and after the match.

It is also assumed that there are differences between the perceptions of players from different countries regarding the leadership behavior of coaches, which could highlight certain particularities of the social, educational, and sporting context in each country.

Transformational leadership has been associated with stronger team resilience and positive relationships, whereas controlling behaviours may increase psychological fatigue (Karayel, 2024; Liu et al., 2025).

## MATERIAL AND METHOD

### Participants

This study analyzed the perceptions of soccer players regarding the behavior of head coaches of U15 national soccer teams in Romania, Montenegro, Greece, and Ireland, aged between 36 and 58.

The coaches from Romania, Montenegro, and Greece hold UEFA A licenses, while the coach from Ireland holds a UEFA PRO license.

The study also included 82 players aged between 14 and 15 who are members of their country's U15 national team. No distinction was made between starters and substitutes; all players who participated in at least two U15 national team matches were included in the study, a criterion chosen to ensure a minimum level of interaction with the coach and, implicitly, a sufficiently clear perception of his behavior. Before data collection commenced, participants received information regarding the purpose of the study, the voluntary nature of participation, and the confidentiality of their responses. Verbal informed consent was obtained from all adult participants. For minors, verbal informed consent was obtained from parents or legal guardians, and verbal assent was obtained from the minors themselves. Verbal informed consent was chosen due to the organizational context of international tournaments and the minimal-risk nature of the study, which involved the completion of anonymized questionnaires without any intervention. The study was approved by the Ethics Committee of the West University of Timișoara, Faculty of Physical Education and Sport (Approval No. 66512/01.10.2025). All procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki.

The measurement tool used in this study was the Multidimensional Scale of Leadership (MSLS).

The Multidimensional Scale of Leadership was used for the first time in sports contexts (Gomes, 2008; Gomes & Resende, 2014; Gomes et al., 2021), assessing athletes' perceptions of coaches' leadership behaviors.

The MSLS includes nine subscales and 36 items grouped into nine subscales (Vision, Inspiration, Instruction, Individualization, Support, Positive Feedback, Negative Feedback, Active Management, Passive Management), each consisting of four items rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

### Data analysis

The statistical analysis was performed using DataTab software. Descriptive statistics were calculated for all variables.

To compare players' perceptions across the four national teams, the non-parametric Kruskal–Wallis test was applied, as the data were ordinal and did not meet the assumptions of normal distribution. When statistically significant differences were identified, Dunn–Bonferroni post-hoc tests were conducted to determine pairwise differences between groups.

The level of statistical significance was set at $p < .05$.

## RESULTS

We assessed the internal consistency of the MSLS using Cronbach's alpha for pre- and post-match data (Table 1). Coefficients ranged from .42 to .94, reflecting varying levels of reliability across subscales.

**Table 1.** Internal Consistency of the Multidimensional Scale of Leadership in Sport (MSLS)

| Subscale | Cronbach's α (Pre) | Cronbach's α (Post) | Interpretation |
|---|---|---|---|
| Vision | 0.83 | 0.71 | Good-Acceptable |
| Inspiration | 0.87 | 0.60 | Excellent – Marginal |
| Instruction | 0.81 | 0.42 | Good-Poor |
| Individualization | 0.91 | 0.80 | Excellent – Good |
| Support | 0.87 | 0.80 | Excellent – Good |
| Positive Feedback | 0.87 | 0.78 | Excellent – Acceptable |
| Negative Feedback | 0.91 | 0.94 | Excellent(both) |
| Active Management | 0.83 | 0.80 | Good(both) |
| Passive Management | 0.63 | 0.73 | Marginal – Acceptable |
| Total Scale (36 items) | 0.90 | 0.78 | Excellent – Acceptable |

*Note. Cronbach's alpha coefficients were calculated separately for pre-match and post-match responses (n = 82 players). Reliability values ranged from .42 (Instruction – post) to .94 (Negative Feedback – post), indicating acceptable to excellent internal consistency across the nine leadership dimensions. The total MSLS scale showed excellent reliability before the match (α = .90) and acceptable reliability after the match (α = .78). Lower reliability coefficients for some subscales, such as Instruction and Inspiration, may be explained by the young age of participants and differences between pre- and post-match assessments. These factors can influence how players interpret and respond to certain items.*

Results showed statistically significant differences between players' perceptions in different countries on the following subscales:

- Vision: Players from Romania rated coaches' behavior significantly more positively than those from Montenegro, Greece, and Ireland, both before and after the competition.
- Inspiration: The highest scores were reported by Romanian and Irish players, while Montenegro recorded the lowest scores.
- Instruction: Romania scored significantly higher than the other countries.
- Individualization: Irish players reported the highest scores, while Montenegro players reported the lowest.
- Support: Romania achieved the highest scores, with significant differences compared to Montenegro and Greece.
- Positive feedback: The highest scores were recorded in Romania, followed by Ireland, while Montenegro had the lowest scores.
- Negative feedback: Montenegro recorded the highest scores, suggesting a more authoritarian leadership style. Romania and Ireland had lower scores.
- Active management: Differences were moderate, but Ireland had relatively higher scores.
- Passive management: Montenegro had the highest scores, indicating a more negative perception of coach involvement.

Overall, Romania and Ireland were rated positively on most leadership dimensions, while Montenegro was consistently associated with lower scores on constructive dimensions and higher scores on negative ones.

## DISCUSSION

The results obtained in this study highlight significant differences between the perceptions of players from four U15 national teams (Romania, Montenegro, Greece, and Ireland) regarding the leadership behavior of their coaches. Data collection was conducted between February and April 2025, during two international tournaments involving the Romanian U15 national team, a context that should be considered when interpreting the findings. The analysis performed with the Kruskal-Wallis test, followed by Dunn-Bonferroni post-hoc tests, showed that these differences are present in most of the MSLS questionnaire subscales. Our findings are consistent with previous results showing that supportive coach behaviours enhance motivation, while controlling behaviours undermine it (Şenel et al., 2025).

### Vision subscale

Players' perceptions of their coach's ability to provide clear direction and a shared vision for the team varied significantly between countries, both before and after the competition. For example, at both time points, players from Montenegro rated this dimension significantly lower than the other participants.

This result may suggest a difference in how the common goal is communicated and internalized within national teams, but caution is needed in drawing causal interpretations. Previous studies support the importance of this dimension in strengthening collective cohesion and effectiveness (Fransen et al., 2018).

Similarly, perceptions of the coach's leadership behavior can change over the course of the season depending on perceptions of team performance and goal achievement (Gomes et al., 2019).

### Inspiration subscale

This dimension, associated with the coach's ability to motivate and enthuse the team, also showed significant variations between groups. Montenegro and Greece had lower scores compared to Ireland and Romania, before and after the competition. The differences may reflect both cultural leadership styles and different levels of inspirational communication practiced in the national context.

The literature shows that inspirational style is a central component of transformational leadership, with positive effects on athletes' engagement and satisfaction (Bass & Riggio, 2006; Mallett, 2010).

### Instruction subscale

Perceptions of the clarity and effectiveness of the technical and tactical instructions provided by the coach varied between countries, especially before matches. In this case, the higher scores obtained by Ireland and Montenegro may suggest a more directive coaching style focused on task clarity.

Well-structured coaching styles correlate positively with collective effectiveness, especially in a competitive context (Høigaard et al., 2015).

### Individualization subscale

This dimension proved to be one of the most differentiated between groups. The higher scores recorded by Montenegro and Ireland may reflect a greater concern for the individual needs of athletes. The perception of individualized support contributes to intrinsic motivation and long-term commitment (Horn, 1985).

### Support subscale

Perceived support from the coach was higher in Ireland and Romania. These data can be related to the literature that emphasizes the role of social support in building coach-athlete relationships (Jowett, 2017; Erickson & Côté, 2016).

### Subscales related to feedback and management

Positive feedback – High scores in Ireland and Romania suggest a leadership style more oriented towards positive reinforcement, which is supported by literature highlighting the beneficial effects of this style on performance (Chen & Rikli, 2003).

Negative feedback – Montenegro scored highest on this subscale, which could signal a more critical or directive communication style. Studies show that frequent negative feedback can affect intrinsic motivation (Horn, 1985).

Active Management – Ireland and Romania also report the best scores on this subscale, while Greece and Montenegro have lower scores.

Passive Management – Montenegro had the highest scores, which may suggest a lack of involvement on the part of coaches in preventing problems or correcting errors.

The results of our study highlighted significant differences between the perceptions of players from the four national teams (Romania, Montenegro, Greece, and Ireland), suggesting a possible influence of cultural and educational context on how coaches' leadership behavior is perceived. These differences should not be interpreted as being exclusively determined by the environment of origin, but reflect, to a certain extent, the impact of social norms, collective values, and communication styles specific to each country.

In this regard, the literature provides a solid theoretical basis. For example, sport leadership is deeply shaped by the cultural context, as athletes' values and expectations can vary significantly from one culture to another (Liu et al, 2025). Similarly, two studies show that players' preferences for certain leadership styles are influenced not only by personal traits, but also by the educational and organizational environments in which they were formed (Horn, 1985; Fransen et al., 2018)

Coaches' personal values are not separate from their daily behaviors, but rather "manifest themselves through concrete actions in their relationship with athletes." This link between values and behavior is important in an educational environment geared toward the holistic development of young athletes (Høigaard et al., 2008).

In addition, the literature on coach development argues that reflective practice plays a central role in shaping an effective and adaptable leadership style (Bell, 2022; Nelson et al., 2006; Knowles et al., 2001). This approach requires coaches to critically evaluate their own actions, adapt to the needs of athletes, and align their behavior with personal and group values.

Therefore, we can assume that the cultural and educational environment influences both the behavior of coaches and how it is perceived by players. However, it should be noted that our study cannot demonstrate a direct causal relationship between these variables. Rather, the results provide a valuable exploratory basis for future cross-cultural research in the field of youth sports leadership.

In order to analyze the intercultural differences between the countries participating in this study, it is important to mention the works of Daniel David (2015) and Geert Hofstede (2010).

Daniel David (2015) describes Romanian culture as characterized by distrust of authority, avoidance of uncertainty, strong relational orientation, and family-based rather than institutional collectivism.

These characteristics can directly influence how Romanian players perceive the behavior of soccer coaches.

Therefore, leadership behaviors perceived as empathetic, supportive, and focused on interpersonal relationships are evaluated positively, while more authoritarian styles are viewed with restraint. In this sense, the results of this study suggest that Romanian players respond favorably to transformational behaviors, especially those related to individual support and positive feedback.

Furthermore, cultural differences between groups in other countries can be analyzed through the cultural model developed by Geert Hofstede.

According to Hofstede et al. (2010), Romania is characterized by uncertainty avoidance and a moderate distance from power, which may indicate a preference for leaders who provide clarity, structure, and support.

Ireland, in comparison with Romania, is defined by a high level of individualism and a low distance from power, which encourages a participatory leadership style characterized by constructive feedback and open communication. This is also reflected in the results of our study. The high scores obtained by the Irish coach in the subscales relating to support for players and the use of positive feedback highlight the cultural model preferred by the Irish people.

According to Hofstede et al. (2010), Greece, like Romania, has a high level of uncertainty avoidance, which can translate into a preference for clear rules and stability. For this reason, players may perceive transactional behaviors more favorably. Montenegro is not directly included in Hofstede's cultural analysis. Still, his theory mentions the people of the Western Balkans, who are characterized by rigid collectivism, a great distance from power, and low tolerance for ambiguity. These characteristics may explain the more authoritarian style perceived by the Montenegro coach and the lower level of appreciation in the dimensions of vision, inspiration, or support.

## CONCLUSIONS

This study highlighted significant differences in the perceptions of U15 players from four European countries (Romania, Greece, Montenegro, and Ireland) regarding the leadership behavior of their coaches. The use of the MSLS questionnaire and the Kruskal-Wallis test allowed these differences to be identified within nine relevant subscales: vision, inspiration, instruction, individualization, support, positive feedback, negative feedback, and active management and passive management.

The results showed that, in most of the dimensions analyzed, players' perceptions varied significantly according to their nationality, suggesting a possible influence of cultural and educational context on how athletes perceive and interpret coaches' behaviors.

Another important conclusion is that players' perceptions are not static but can change depending on their experiences in competition. This was observed by comparing pre- and post-competition responses, which revealed some significant changes in the evaluation of the coach's behavior, especially in dimensions such as inspiration or positive feedback. Thus, the coach-player relationship should be understood as dynamic, influenced by context and results, but also by how the coach communicates, supports, and manages the team.

Although the study did not directly assess the influence of the cultural environment through in-depth qualitative or transnational comparative methods, the differences observed between countries indicate that cultural variables and educational styles may contribute to how leadership behaviors are perceived and appreciated. This highlights the need for coach training programs that integrate components of cultural adaptability and critical reflection on one's own behaviors and values.

The results of this study, which was based on analyzing players' perceptions of the leadership behavior of coaches of U15 national teams in Ireland, Montenegro, Greece, and Romania, highlight significant differences that can be correlated with cultural, educational, and structural characteristics of each football context.

The Romanian coach stands out for his balanced and active leadership style, which is perceived positively by the players. The Montenegrin coach is in stark contrast, with a more rigid and authoritarian style, while Ireland and Greece are positioned between these extremes, with rather positive tendencies in the case of Ireland and neutral tendencies in the case of Greece.

In conclusion, this study contributes to the literature by providing a comparative perspective on how young football players perceive coaching leadership in different cultural contexts. The results may be useful for national federations, coach educators, and practitioners in high-performance sport who wish to improve the coach-player relationship and promote an effective leadership style tailored to the real needs of young athletes.

## Limitations of the study

### *Subjective assessment of coaches' behavior*

The data were based solely on the players' perceptions, without any external or observational assessment of the coaches' behaviors. Future studies may benefit from using observational tools to complement self-report measures, as suggested by comparative analyses of coach behaviour observation instruments (Ordeix et al., 2023).

### *Influence of the competitive context*

The questionnaires were completed close to the time of the competition, which may have influenced the participants' perceptions, especially depending on the results or the atmosphere created during the tournament.

### *Sample size*

Although acceptable for exploratory research, the number of participants is relatively limited to generalize conclusions to the entire population of U15 players or to each country involved.

## AUTHOR CONTRIBUTIONS

All authors contributed to the design, data collection, statistical analysis, and writing of the manuscript. All authors approved the final version of the paper.

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## CONFLICT OF INTEREST

The authors report there are no competing interests to declare.

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# Supervised vs. Unsupervised Training: A Comparative Analysis of Push-up, Sit-up, and Squat Improvements

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**ABSTRACT.** ***Introduction:*** Supervised physical training enhances adherence, technique, and muscular adaptation, whereas many university students rely on unguided routines that may limit progress in basic bodyweight exercises. Prior research shows that structured programs (especially those using progressive overload, circuit training, and high-intensity formats) produce superior gains in muscular endurance. ***Objective***: This study aimed to compare the effects of an eight-week supervised program with unguided training on push-up, sit-up, and squat performance in non-sport major university students. ***Material and methods***: Fifty-three students were randomly allocated to a supervised training group (n = 25) or a control group (n = 28), with comparable gender distributions. All participants completed standardized pre/post assessments, and the intervention group performed structured sessions integrating progressive overload, circuit training, and AMRAP, while controls trained independently. ***Results***: The supervised group showed markedly greater improvements, gaining +5.52 push-ups, +9.68 sit-ups, and +15 squats, compared to the control group's +2.46, +3.11, and +6.39. Percentage increases were 2–3 times higher in the supervised group, and regression models identified supervised participation as the strongest predictor of improvement, independent of sex, BMI, anthropometrics, or baseline fitness. ***Conclusion***: An eight-week supervised program built on progressive overload, circuit structures, and AMRAP leads to substantially greater muscular endurance gains than unguided training in university students. The findings underscore the value of structured, instructor-led approaches for enhancing basic bodyweight performance.

***Keywords:*** *supervised training; AMRAP; university students; intervention study*

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## INTRODUCTION

The importance of structured physical training for enhancing fundamental fitness capacities is well established among young adults with diverse baseline activity levels (Fennell et al., 2016). Evidence consistently shows that supervised programs lead to superior adherence, technique execution, and muscular adaptations compared with unsupervised formats in older adults, recreational lifters, and university cohorts (Lacroix et al., 2017; McNeil et al., 2015). Unsupervised routines, although useful for accessibility, often yield weaker strength outcomes, particularly in technically demanding tasks such as push-ups or sit-ups (Mahjur & Norasteh, 2021; Emerenziani et al., 2014). Structured training programs, supported by systematic instruction and targeted feedback, have been shown to produce superior improvements in motor performance and physical capacities compared to unstructured or self-directed practice, particularly in educational and youth sport contexts (Gherman et al., 2025). Growing interest in high-intensity functional or multimodal exercise further highlights the need for structured prescription, as inconsistent progression can reduce effectiveness in self-guided training (Sobrero et al., 2016; Sharp et al., 2024). School- and university-based studies show that circuit, resistance, or combined endurance–strength interventions substantially improve muscular endurance and body composition when systematically supervised (Stojanović et al., 2023; Pérez-Ramírez et al., 2024). Remote HIIT programs can still produce endurance benefits, though autonomic and strength adaptations remain more variable without direct oversight (García-Suárez et al., 2022). Recent educational research emphasizes that well-designed instructional strategies and supervised practice environments facilitate more efficient skill acquisition and performance improvements than unsupervised training, even when exercise content remains relatively simple (Gherman et al., 2025). Across youth and adult populations, whole-body HIIT and multimodal circuit formats demonstrate balanced improvements in endurance and strength (Bossmann et al., 2022; Falk Neto & Kennedy, 2019). At the same time, methodological analyses emphasize that standardized reporting of volume, intensity, and adherence is crucial for valid comparisons between training conditions (Liu et al., 2020). Training response is also shaped by baseline fitness, BMI, and sex-related physiological differences, with lower-fit individuals often showing greater proportional progress (Pihlainen et al., 2020; Mwebaze et al., 2025). Empirical evidence from applied sports science highlights that structured interventions allow for better control of training variables, improved adherence, and more reliable performance outcomes compared to freely chosen training routines (Gherman et al., 2018). In collegiate settings, daily activity patterns further predict performance in basic muscular endurance tests such as push-ups, sit-ups, and squats (Heinrich et al., 2022; Edman et al., 2013). Considering these factors, this study examines whether an eight-week supervised program using progressive overload, circuit training, and AMRAP produces greater improvements in push-up, sit-up, and squat performance than unguided training among non-sport major university students. General physical education lessons should be structured to generate diverse problem-solving situations, thereby fostering the development of memory, balance, spatial orientation, and movement coordination through the effective and purposeful use of physical activities (Prodea & Karacsony, 2022).

## MATERIALS AND METHODS

### Participants

The study included 53 university students from non-sport faculties, assigned to either a control group or a supervised training group. Participants differed in gender, height, weight, and baseline fitness, forming a heterogeneous yet representative student sample. All completed standardized push-up, sit-up, and squat tests before and after the eight-week intervention. The supervised group followed a structured program, whereas the control group trained independently or minimally, enabling a clear comparison of performance improvements.

### Training methods used in the intervention

For non-sport major students, these three methods balance safety, simplicity, and measurable progression without requiring advanced motor skills. Progressive overload creates steady improvements with minimal physiological stress, while circuit training offers variety and improved general conditioning. AMRAP provides a reliable performance metric that is easy to track across testing sessions. In contrast, HIIT, Tabata, EMOM, and failure-based methods demand higher technical proficiency, impose greater metabolic strain, and can discourage low-fitness participants. Therefore, the chosen methods maximize adherence and performance gains while minimizing risk, making them ideal for this type of sample.

### Research design

The research used a quasi-experimental pre–post design with two groups: a supervised training group and a control group. Participants were randomly assigned to reduce selection bias, and both groups completed identical baseline and post-intervention tests. The control group trained independently in any manner they chose and was kept separate from the supervised group to avoid cross-influence. The intervention group followed a structured program using progressive overload, circuit training, and AMRAP, enabling a clear comparison between guided and self-directed training.

### Regression framework and control variables

This section expands explanation by incorporating all control variables included in the regression models, specifically MALE, HEIGHT_CM, WEIGHT_KG, and BMI, which also play an important role in producing unbiased estimates of training effects. Regression analysis offers substantial advantages over simple mean-difference comparisons because it allows the model to statistically control for participant-level characteristics that may influence performance independently of the training intervention. Differences in body composition, anthropometrics, and gender-based physiological capacity can create systematic variation in performance outcomes. By including these variables, regression isolates the causal contribution of the supervised training program more accurately. The general regression equation, applicable to all six models (three absolute gains and three percentage gains), is specified as:

$$Y_i = \beta_0 + \beta_1 \cdot TRAINING_i + \beta_2 \cdot MALE_i + \beta_3 \cdot HEIGHT\_CM_i + \beta_4 \cdot WEIGHT\_KG_i + \beta_5 \cdot BMI_i + \beta_6 \cdot PUSHUPS\_PRE_i + \beta_7 \cdot SITUPS\_PRE_i + \beta_8 \cdot SQTS\_PRE_i + \varepsilon_i$$

In this formulation, $Y_i$ refers to one of the dependent variables: PUSH_GAIN, PUSH_%, SIT_GAIN, SIT_%, SQT_GAIN, or SQT_%. $TRAINING_i$ is the intervention indicator, while $MALE_i$ controls for sex-related physiological differences that may influence strength, endurance, or adaptation rates. The variables $HEIGHT\_CM_i$ and $WEIGHT\_KG_i$ capture anthropometric differences that affect leverage, limb length, or body mass loading during exercise execution. $BMI_i$ integrates height and weight into a standardized measure of body composition that influences mechanical effort and aerobic efficiency. The variables PUSHUPS_PRE, SITUPS_PRE, and SQTS_PRE capture baseline performance levels. Including these variables ensures that the regression estimates training effects net of initial ability. This is essential because individuals with higher initial scores may have less potential for improvement, while those with low baselines may exhibit larger proportional gains independent of training quality. Together, these variables form a comprehensive statistical framework that controls for demographic, anthropometric, and baseline fitness differences. This allows the regression models to quantify the true contribution of the supervised training program with greater accuracy and methodological rigor.

## RESULTS

### Descriptive statistics and summary of participant data

This report presents descriptive statistics, numerical summaries, and visualizations based on a dataset of 53 participants, divided into a Control group (N = 28) and a Training group (N = 25). Variables include demographic data (height, weight, BMI) and performance measures for push-ups (PUSHUPS_PRE, PUSHUPS_POST), sit-ups (SITUPS_PRE, SITUPS_POST), and squats (SQTS_PRE, SQTS_POST), with individual percentage improvements and group/sex comparisons provided descriptively. Table 1 shows moderate baseline fitness levels: mean PUSHUPS_PRE = 14.13 (SD = 4.37), increasing to 18.04 (SD = 5.79) after eight weeks. SITUPS_PRE averaged 24.4 (SD = 4.66) and rose to 30.6 (SD = 7.05), while SQTS_PRE increased from 37.91 (SD = 7.11) to 48.36 (SD = 11.31), the largest absolute gain, consistent with strong lower-body responsiveness. Anthropometric values averaged 170.85 cm (SD = 8.84) for height and 70.24 kg (SD = 11.16) for weight, with a mean BMI of 24.09 (SD = 3.65), typical for university-aged adults. Improvements across all exercises indicate broad physical gains, while higher post-test SDs reflect expected variability in mixed-sex, non-athlete samples. Overall, the descriptive results confirm meaningful increases in muscular endurance and strength over the intervention period.

**Table 1.** Descriptive Statistics

| Variable | Mean | SD | Min | Max |
|---|---|---|---|---|
| HEIGHT_CM | 170.85 | 8.84 | 151.0 | 199.0 |
| WEIGHT_KG | 70.24 | 11.16 | 45.2 | 109.8 |
| BMI | 24.09 | 3.65 | 18.0 | 33.8 |
| PUSHUPS_PRE | 14.13 | 4.37 | 3 | 27 |
| PUSHUPS_POST | 18.04 | 5.79 | 5 | 34 |
| SITUPS_PRE | 24.40 | 4.66 | 10 | 40 |
| SITUPS_POST | 30.60 | 7.05 | 13 | 49 |
| SQTS_PRE | 37.91 | 7.11 | 20 | 58 |
| SQTS_POST | 48.36 | 11.31 | 24 | 78 |

### Sex-based comparison of performance gains

Table 2 shows that female participants achieved slightly higher percentage improvements than males in push-ups (PUSH_INC: 29.55% vs 26.3%), sit-ups (27.71% vs 23.51%), and nearly identical gains in squats (27.39% vs 27.15%). A likely explanation is that females typically begin with lower baseline values—especially in upper-body tasks—which allows larger relative gains even when absolute increases are similar (e.g., +3 reps from 10→13 equals +30%, while 20→23 equals +15%). The greater sit-up improvements for women (27.71% vs 23.51%) may also reflect stronger adherence or comfort with core-based exercises, which can enhance training quality. The near-equal squat gains (27.39% vs 27.15%) indicate robust lower-body adaptation in both sexes, as multi-joint lower-limb exercises elicit strong responses regardless of gender. Physiologically, men's higher muscle mass and strength can produce smaller relative percentage gains under identical training loads due to a "ceiling effect," whereas women may show larger proportional improvements when progressing from low to moderate levels over an eight-week period.

**Table 2.** Percentage improvements by gender

| Gender | PUSH_INC | SIT_INC | SQT_INC |
|---|---|---|---|
| Female | 29.55 | 27.71 | 27.39 |
| Male | 26.3 | 23.51 | 27.15 |

### Descriptive visualization of training-related changes

The combined boxplot (Figure 3) provides clear visual and numerical evidence of improvement across all exercises from pre- to post-testing. For push-ups, the median rises from about 13–14 reps to around 18, with the upper whisker increasing from roughly 23 to 27–31 reps, indicating strong performers also progressed. Sit-ups show a pre-test median of 24–25 reps increasing to about 30, while the upper whisker grows from 35–36 to approximately 46–49 reps, reflecting higher central values and greater variability. Squats, which begin with the highest baseline scores, show the largest absolute change: the median climbs from roughly 38–39 reps to around 48, and the upper whisker extends dramatically to 70–78 reps, suggesting strong lower-body adaptation in some individuals. Across all exercises, slightly wider post-test IQRs indicate broader individual progress due to variation in adherence and baseline fitness. Overall, the boxplot trends match the descriptive statistics, showing upward median shifts, higher maxima, and modest variability increases over the 8-week period.

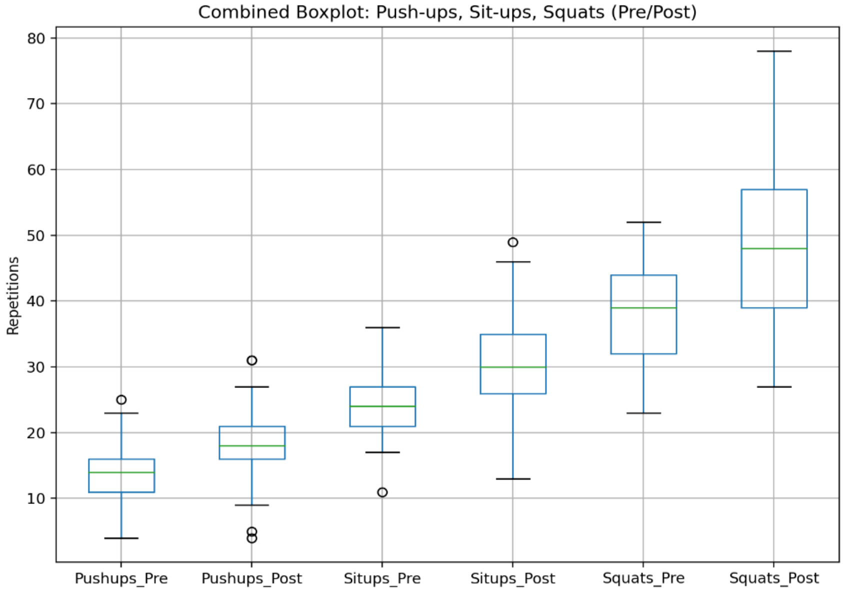


**Fig. 3.** Combined Boxplot of Pre/Post Performance Across all Exercises

### Group differences in performance gains: Welch's t-test analysis

Based on the available data, both absolute and percentage performance gains were analyzed to compare the Training group (three-method program) with the Control group (free training). Welch's t-tests showed large and significant absolute differences: PUSHUPS increased by 5.52 reps in Training vs 2.46 in Control ($t = 5.68$, $p = 1.36 \times 10^{-6}$); SITUPS rose by 9.68 vs 3.11 ($t = 8.98$, $p = 5.19 \times 10^{-11}$); and SQUATS improved by 15 vs 6.39 ($t = 6.12$, $p = 6.98 \times 10^{-7}$). Percentage changes amplified these differences: PUSH_INC reached 40.89% in Training vs 16.40% in Control ($t = 7.99$, $p = 1.12 \times 10^{-9}$); SIT_INC averaged 38–41% vs 13–15% ($t = 10.58$, $p < 10^{-11}$); and SQUAT_INC was 36–37% vs 19% ($t = 6.40$, $p \approx 10^{-6}$). Sex-specific analyses aligned with overall results. Among men, absolute gains were significantly larger in Training ($t \approx 4.5$–$6.0$, $p < .001$), and percentage improvements were two to three times higher than in Control. Among women, relative differences were even stronger: PUSH_INC = +42.4% vs 15.7% ($t = 6.66$, $p = 1.23 \times 10^{-6}$), SIT_INC = +41.3% vs 13.06% ($t = 6.48$, $p = 1.83 \times 10^{-6}$), and SQUAT_INC = +35.23% vs 18.95% ($t = 3.59$, $p = .002$). Overall, both absolute and percentage analyses—whether for the full sample or split by sex—show that the supervised three-method program produced substantially greater improvements than the unstructured training of the Control group.

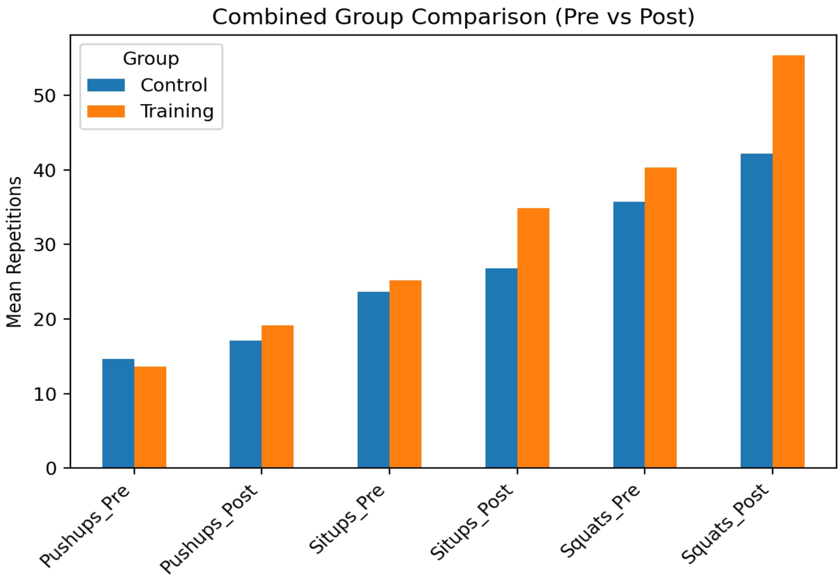


**Fig. 4.** Mean Performance Comparison Between Training and Control Groups

## Interpretation of regression results

The results presented in Table 3 indicate that TRAINING is consistently the strongest and most significant predictor across all six regression models. The coefficients are large and positive—for example, 3.38 for PUSH_GAIN, 24.81 for PUSH_%, 6.11 for SIT_GAIN, and 20.56 for SQT_%, confirming a robust training effect (all $p < .001$). In contrast, MALE is not statistically significant in any model, with small coefficients such as –0.46 for PUSH_GAIN, indicating no meaningful association with performance changes. HEIGHT_CM likewise shows negligible influence, with coefficients near zero (e.g., –0.08 for PUSH_GAIN, –0.22 for SIT_GAIN), suggesting height does not explain improvements in repetitions. WEIGHT_KG also lacks predictive value, with small, nonsignificant coefficients such as 0.15 for PUSH_GAIN and –0.50 for SQT_GAIN. Similarly, BMI exhibits minor nonsignificant effects, –0.47 for PUSH_GAIN and –1.17 for SIT_%, indicating no contribution to outcome variation. The baseline variables show exercise-specific patterns: PUSHUPS_PRE is significant in the PUSH_GAIN model (0.27, $p < .001$), meaning initial push-up performance partly predicts absolute gains, though it remains nonsignificant for PUSH_%. SITUPS_PRE has a moderate significant effect on SIT_GAIN (0.18, $p < .05$) but a nonsignificant negative trend for SIT_%. SQTS_PRE is nonsignificant in both SQT models. The CONST terms are large and nonsignificant, providing no interpretive value. Overall, the regression results clearly show that TRAINING is the dominant factor driving improvements across all exercises, while demographic and anthropometric variables contribute little or not at all.

**Table 3.** Regression Coefficients for Absolute and Percentage Gains in All Exercises

| Variable | PUSH_GAIN | PUSH_% | SIT_GAIN | SIT_% | SQT_GAIN | SQT_% |
|---|---|---|---|---|---|---|
| CONST | 13.28 | 99.87 | 28.26 | 136.50 | -80.97 | -185.99 |
| | (0.43) | (0.45) | (0.60) | (0.72) | (-0.80) | (-0.74) |
| TRAINING | ***3.38 | ***24.81 | ***6.11 | ***25.77 | ***8.07 | ***20.56 |
| | (7.96) | (7.99) | (9.32) | (9.72) | (5.48) | (5.62) |
| MALE | -0.46 | -3.42 | -0.13 | -0.70 | 0.63 | 1.67 |
| | (-0.64) | (-0.64) | (-0.12) | (-0.17) | (0.29) | (0.31) |
| HEIGHT_CM | -0.08 | -0.45 | -0.22 | -0.81 | 0.45 | 1.19 |
| | (-0.45) | (-0.35) | (-0.79) | (-0.72) | (0.78) | (0.82) |
| WEIGHT_KG | 0.15 | 0.73 | 0.25 | 0.80 | -0.50 | -1.40 |
| | (0.72) | (0.48) | (0.75) | (0.61) | (-0.72) | (-0.81) |
| BMI | -0.47 | -2.48 | -0.39 | -1.17 | 1.65 | 4.48 |
| | (-0.77) | (-0.55) | (-0.41) | (-0.30) | (0.82) | (0.89) |
| PUSHUPS_PRE | ***0.27 | 0.24 | - | - | - | - |
| | (4.77) | (0.58) | | | | |
| SITUPS_PRE | - | - | *0.18 | -0.51 | - | - |
| | | | (2.47) | (-1.73) | | |
| SQTS_PRE | - | - | - | - | 0.13 | -0.28 |
| | | | | | (1.20) | (-1.00) |

## DISCUSSION

The supervised program in this study produced substantially greater gains in push-ups, sit-ups, and squats than unguided training, echoing prior evidence that structured guidance enhances muscular endurance (Fennell et al., 2016; Lacroix et al., 2017). Like findings by McNeil et al. (2015), the superior results of the supervised group suggest that consistent instruction and progression are key factors in driving strength adaptations. In contrast, the minimal improvements seen in the control group align with studies showing limited effectiveness of unsupervised routines, such as those reported by Mahjur and Norasteh (2021). The present findings are consistent with previous research indicating that supervised and systematically designed training programs lead to greater neuromuscular and performance adaptations than unsupervised approaches, regardless of participants' initial fitness levels (Gherman et al., 2018). The strong increases in squat performance mirror the robust lower-body adaptations observed in school-based circuit training studies (Stojanović et al., 2023), although our university sample displayed even larger absolute improvements. Similar to results reported in educational and applied sport studies, the effectiveness of the supervised program in the present research suggests that structured guidance may outweigh individual anthropometric or demographic factors in determining short-term training adaptations (Gherman et al., 2025).

The patterns of percentage gains in the supervised group also resemble responses reported in structured high-intensity functional training, despite our use of simpler methods (Sobrero et al., 2016). Regression analyses demonstrated that TRAINING was the dominant predictor of improvements, consistent with the broader conclusion of Sharp et al. (2024) that program structure outweighs participant characteristics in determining adaptation. Unlike the findings of Pihlainen et al. (2020), our models showed no significant influence of BMI or baseline anthropometrics, suggesting a more uniform response in this young adult cohort. Although sex was not a significant predictor in regression results, the slightly higher relative gains among women correspond partly with physiological trends described by Mwebaze et al. (2025). The variability seen in post-test scores resembles patterns noted in studies of remote or variable-intensity training (García-Suárez et al., 2022), though in our case likely reflects differences in adherence rather than program inconsistency.

## CONCLUSIONS

This study showed that an eight-week supervised program using progressive overload, circuit training, and AMRAP produced significantly larger improvements in push-ups, sit-ups, and squats than unguided training in non-sport major university students. The supervised group achieved both higher absolute increases and markedly greater percentage gains, confirming the clear advantage of structured instruction. Regression analyses reinforced this finding by identifying TRAINING as the strongest predictor across all performance outcomes, independent of sex, BMI, or anthropometric characteristics. An original contribution of this study is the combined use of three simple, low-technical training methods within a supervised model specifically tailored for non-athlete university populations. The results also provide practical evidence that accessible bodyweight-based programs can yield substantial fitness gains when implemented with guidance.

However, the study has limitations, including a relatively small sample size, reliance on self-reported adherence in the control group, and the absence of long-term follow-up to assess retention of gains. Another limitation is that training intensity was not objectively quantified, which limits comparisons with more advanced or periodized programs. Future research should explore the effects of supervised versus hybrid (partly supervised) models, as well as technology-supported remote supervision. Longitudinal studies examining how improvements evolve or decline over several months would also be valuable. Additionally, investigating the impact of psychological factors—such as motivation or perceived competence—could further clarify why supervised training is consistently more effective.

## AUTHOR CONTRIBUTIONS

Păuna Răzvan-Dorel, Șerban Rau Tiberiu și Pop Sergiu contributed equally to the design and implementation of the research, to the data collection, analysis and interpretation 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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# Understanding Key Factors in Basketball Dropout

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**ABSTRACT**. Dropout from performance-level sport represents a critical challenge in youth and young adult athletic development, with implications for long-term physical activity and psychological well-being. This study investigates factors associated with withdrawal from performance basketball among former athletes, with particular emphasis on academic demands, psychological experiences, coaching climate, injuries, and post-dropout adjustment. **Objectives:** The primary objective was to identify key individual, psychological, and structural factors influencing dropout from performance basketball and to explore athletes' experiences during and after withdrawal from competitive sport. **Materials and Methods:** A cross-sectional, questionnaire-based study was conducted between 1 and 30 April 2025 on a sample of 48 former performance basketball players (32 women, 16 men), aged 18–29 years. Data were collected online using a 33-item questionnaire developed for this study, informed by existing literature on sport dropout and validated through expert consultation. Descriptive statistical analyses were applied, complemented by categorical analysis of open-ended responses. **Results:** Dropout occurred predominantly during late adolescence, with a mean withdrawal age of 17.5 years, despite early engagement in basketball (mean starting age = 8.91 years). The most frequently reported reasons for dropout were other academic opportunities and perceived lack of progression pathways. Psychological demands were high, while access to psychological support during athletes' careers was limited. Coach-related pressure, injury experiences, and insufficient recovery resources further contributed to withdrawal decisions. Post-dropout experiences included both emotional difficulties and positive life reorientation, with the majority of participants continuing to practice basketball at a recreational level. **Conclusions:** Dropout from performance basketball emerges as

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a multifactorial and transitional process rather than a single negative outcome. The findings underline the need for athlete-centred development models that integrate dual-career support, psychological services, and supportive coaching environments to promote sustainable engagement in sport.

***Keywords:*** *sport dropout, performance basketball, youth athletes, psychological factors, sport participation.*

## INTRODUCTION

Participation in organized sport during childhood and adolescence is widely recognised as a critical contributor to physical health, motor development, and psychosocial well-being. However, a considerable decline in sport participation is observed as young people transition from early adolescence into later teenage years and young adulthood, with participation sometimes decreasing sharply during this developmental period (Lara-Bercial et al., 2025). This phenomenon, commonly referred to as sport dropout, has therefore attracted substantial attention in sport science and public health research as a complex behavioural outcome with implications for lifelong physical activity and health (Zhang et al., 2024).

Despite decades of research, conceptual clarity around dropout remains limited, and the process is now understood as multifaceted, involving intrapersonal, interpersonal, and structural influences rather than a simple loss of interest (Battaglia et al., 2024; Zhang et al., 2024). Systematic reviews have highlighted that multiple discrete factors contribute to dropout, including lack of enjoyment, perceptions of competence, social pressures, competing priorities such as academic demands, and physical concerns such as injury or maturation-related challenges (Back et al., 2022; Crane & Temple, 2015; Zhang et al., 2024). These findings underscore that dropout often reflects a cumulative interplay of factors rather than a single cause.

Motivational and psychological factors play an important role in whether young athletes continue participating in sport or choose to withdraw. Research indicates that athletes are more likely to remain engaged when their basic psychological needs for autonomy, competence and social connection are satisfied, while lower levels of self-driven motivation are associated with an increased risk of dropout (Back et al., 2022; Zhang et al., 2024). Furthermore, social support from coaches, peers, and parents appears to moderate these motivational processes, as supportive environments may enhance intrinsic motivation and foster continued participation (Back et al., 2022). In turn, environments perceived as controlling, stressful, or excessively result-oriented may undermine intrinsic motivation and contribute to decisions to discontinue sport.

In addition to motivational and social factors, the broader sport environment plays a significant role. Systematic evidence suggests that structural elements such as the intensity of training requirements, lack of adaptive developmental pathways, and competing life demands (e.g., academic workload) can influence the likelihood of dropout (Zhang et al., 2024). Moreover, research indicates that dropout is not confined to a single developmental stage; rather, it can occur at multiple transition points, including the shift from youth to late adolescence, when individuals encounter increased academic, social, and personal demands (Lara-Bercial et al., 2025). One of the most frequently reported reasons young people give for withdrawing from organised sport before reaching adulthood is a loss of enjoyment.

Enjoyment has been identified as one of the most common intrinsic motivators for sport participation among children and adolescents; however, it is also repeatedly cited as a key reason for dropout when sport is no longer perceived as pleasurable (Crane & Temple, 2015). Many children and young people initially engage in sport because of the sense of well-being experienced during participation, yet when this experience becomes dominated by pressure, monotony, or negative emotions, the likelihood of withdrawal increases.

In our opinion, performance in basketball is mainly influenced by physical, physiological, and behavioural characteristics, and young athletes who struggle to meet these demands or experience delays in physical, mental, or emotional development may be particularly vulnerable to withdrawal (Soares et al., 2020). Performance pressure and limited opportunities to continue competitive participation beyond certain age levels further intensify dropout risk. Structural constraints, such as local infrastructure, availability of qualified coaches, financial limitations, and challenges related to athlete transfers, may also restrict developmental pathways and contribute to disengagement. Intrapersonal factors such as perceived physical competence also play an important role in the dropout process (Lima et al., 2020). A decline in motivation may occur when young athletes transition into a higher age category, where previously acquired skills are no longer sufficient to meet performance expectations. If these developmental transitions are not adequately explained or supported, athletes may develop feelings of inadequacy or perceive limited potential for improvement, which can contribute to disengagement from sport (Schmid et al., 2023).

Basketball performance depends on physical, physiological, and behavioural factors, and young athletes who struggle to meet these demands or experience developmental delays may be more vulnerable to dropout (Soares et al., 2020). Performance pressure, limited post-youth opportunities, and structural constraints such as infrastructure, coaching availability, financial resources, and transfer barriers can further restrict development and increase disengagement. At the same time, some authors suggest that a diminution in organised sport participation should not always be viewed as a negative outcome, as it can reflect normal developmental changes rather than solely problematic experiences (Battaglia et al., 2024).

## PURPOSE OF THE STUDY

The purpose of the present study is to examine the factors associated with dropout from performance basketball, with particular attention to motivational, psychological, interpersonal, and structural influences experienced during athletes' developmental pathways. Building on contemporary research that conceptualises dropout as a multifactorial and context-dependent process, this study seeks to explore how former basketball players perceive the conditions that contributed to their withdrawal from organised competitive participation.

## MATERIAL AND METHODS

The study employed a cross-sectional, descriptive design using a self-administered questionnaire to examine factors associated with dropout from performance-level basketball. The sample consisted of 48 former basketball players (32 women and 16 men) who had previously performed in Romanian basketball clubs and had discontinued performance participation at the time of data collection.

Data were collected between 1 and 30 April 2025, using a 33-item structured questionnaire administered online via Goggle Forms platform. The questionnaire consisted in demographic characteristics, sport participation history, perceived reasons for withdrawal, and psychosocial experiences related to disengagement from basketball. It was newly developed for this study and conceptually informed by the Youth Sport Dropout Questionnaire proposed by Lara-Bercial et al. (2025), while being adapted to the specific context of performance basketball. Item formats included multiple-choice questions, yes or no ending responses, Likert-type scales, and selected open-ended questions.

Content validity was ensured through consultation with two experts in basketball, with the aim of confirming the relevance and clarity of the items in relation to the study objectives. This approach is consistent with methodological guidelines for context-specific instrument development and adaptation (Boateng et al., 2018). The questionnaire was administered online to ensure accessibility and anonymity, with participation being voluntary and based on informed consent. Data analysis was primarily descriptive, using frequencies, percentages, and measures of central tendency, complemented by qualitative content analysis of open-ended responses to identify recurring themes related to dropout experiences.

## RESULTS

From the findings of the study we will first describe the demographic profile of the participants, followed by an overview of their sport participation background and reported experiences related to withdrawal from performance-level basketball. Demographic data indicate that participants were predominantly in early adulthood, with ages ranging from 18 to 29 years and a concentration of responses in the early twenties. The mean age of the sample was 22.17 years, and the most frequently reported age was 23 years, represented by 13 participants. Participants reported a wide range of ages for the onset of basketball participation. The mean age at which respondents began practicing basketball was 8.91 years, indicating early engagement with the sport. The most frequently reported starting age was 9 years, reported by 15 participants (31%), while one participant began at the age of 5 years and two participants reported a later start at 15 years of age.

Withdrawal from performance-level basketball occurred predominantly during late adolescence. The mean age at dropout was 17.5 years, with the highest concentration of responses at 17 years (n = 14) and 18 years (n = 10). Only one participant reported discontinuation at a later age, 26 years, indicating that dropout most commonly occurred before early adulthood.

**Table 1.** Basketball participation background of the participants

| Variable | Category | n | % |
|---|---|---|---|
| **Years of performance participation** | 1–3 years | 5 | 10.4 |
| | 4–6 years | 15 | 31.3 |
| | 7–10 years | 21 | 43.8 |
| | >10 years | 7 | 14.6 |
| **Highest competition level** | Junior | 12 | 25.0 |
| | High school | 9 | 18.8 |
| | National | 18 | 37.5 |
| | International | 6 | 12.5 |
| | Senior | 3 | 6.2 |

Table 1. presents participants' competitive background, indicating that most respondents accumulated between 7 and 10 years of performance-level experience and competed primarily at national or junior levels.

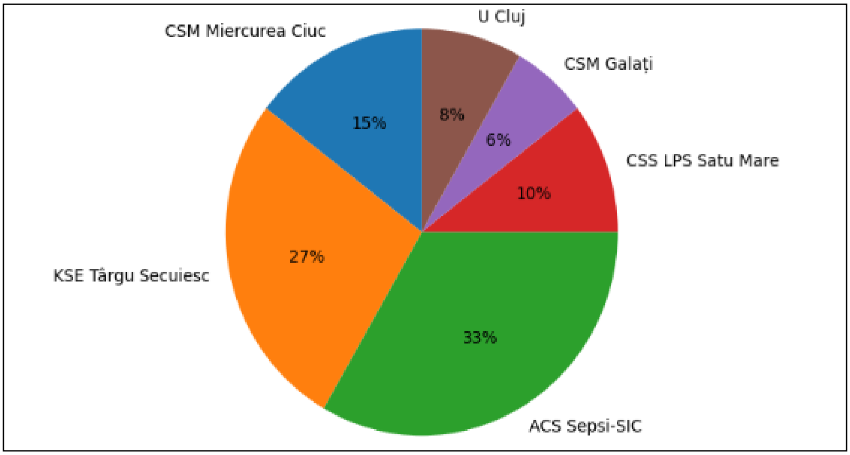


**Fig. 1.** Club affiliation of former performance basketball players

Fig. 1., illustrates the club affiliation of the former performance basketball players included in the study. The largest proportion of participants reported prior involvement with ACS Sepsi-SIC and KSE Târgu Secuiesc, followed by CSM Miercurea Ciuc, while smaller proportions represented CSS LPS Satu Mare, U Cluj, and CSM Galați.

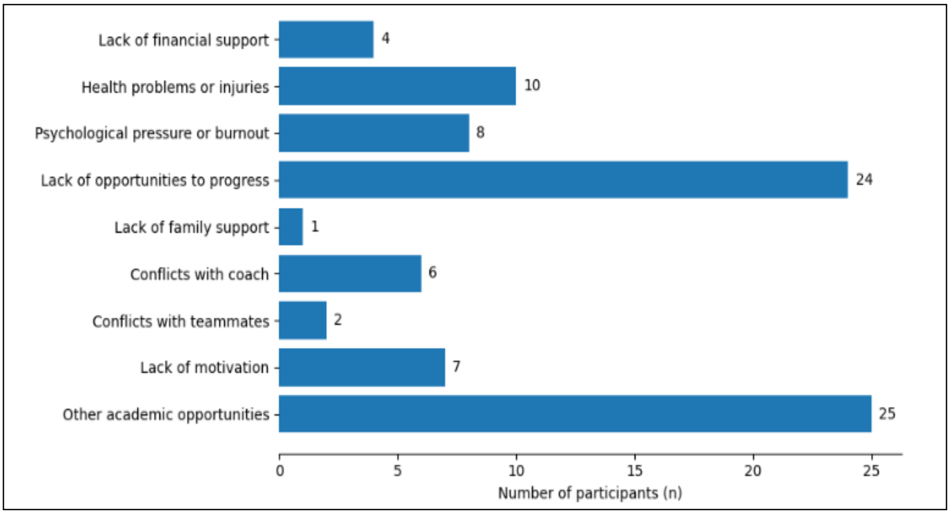


**Fig. 2.** Reasons for dropping out of performance-level basketball

As it is represented in Fig. 2., the main reasons reported for withdrawal from performance-level basketball are the following: Other academic opportunities and the perceived lack of opportunities to progress were the most frequently reported factors, followed by health-related issues, psychological pressure or burnout, and lack of motivation. Factors related to family support and peer conflict were reported less frequently.

**Table 2.** Psychological experiences reported during performance basketball careers

| Item | Response options | % |
|---|---|---|
| **Access to psychological support during career** | Yes | 35.4 |
| | No | 64.6 |
| **Mental preparation considered as important as physical preparation** | Yes | 95.8 |
| | No | 4.2 |
| **Competitive environment perceived as overly stressful** | Yes | 29.2 |
| | Partially | 56.3 |
| | No | 14.6 |
| **Experienced mental overload during career** | Yes | 50.0 |
| | No | 50.0 |
| **Perceived level of psychological pressure** | Very high | 8.3 |
| | High | 39.6 |
| | Moderate | 48.8 |
| | Low | 8.3 |
| **Would have continued sport with greater psychological/emotional support** | Yes | 50.0 |
| | No | 50.0 |

Table 2. summarises participants' psychological experiences during their performance basketball careers, including access to psychological support, perceived mental demands, and evaluations of competitive stress.

As shown in Fig. 3., 60.4% of participants reported experiencing excessive pressure from coaches, while 39.6% did not. Perceived emotional support from coaches was distributed across responses, with 29.2% indicating sufficient support, 39.6% partial support, and 31.3% insufficient support.

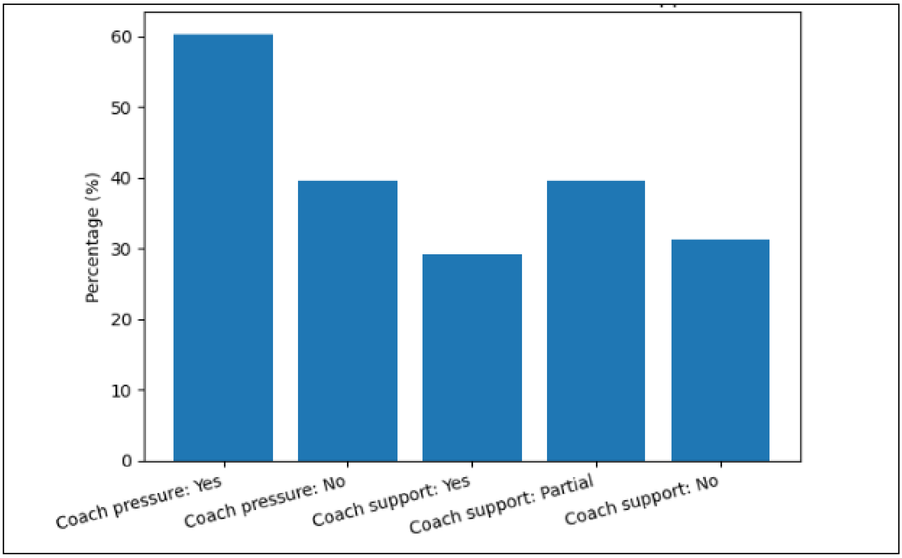


**Fig. 3.** Coach related pressure and emotional support

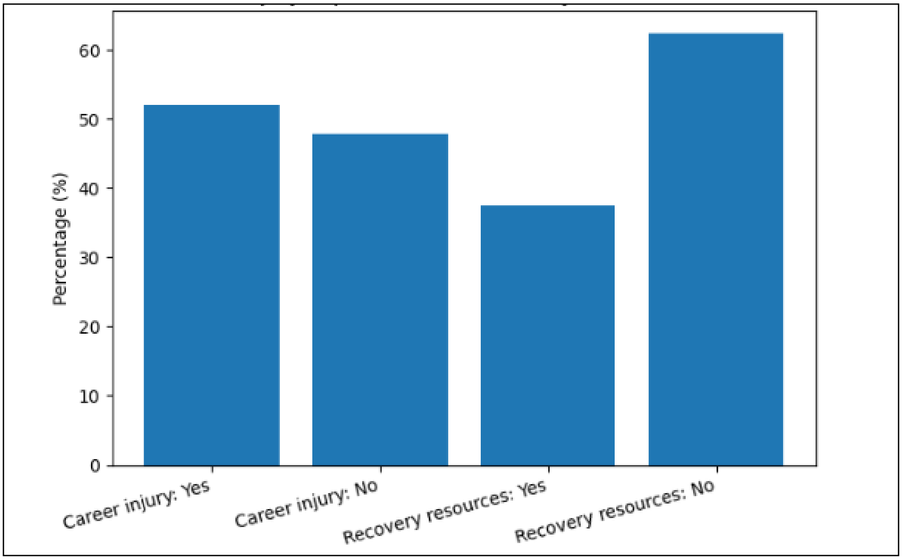


**Fig. 4.** Injury experience and availability of recovery resources during basketball careers

According to Fig. 4., 52.1% of participants reported sustaining injuries that affected their basketball careers, while 47.9% did not. Among respondents, 62.5% perceived recovery resources as insufficient, whereas 37.6% reported adequate resources for injury recovery.

**Table 3.** Post-dropout experiences reported by former performance basketball

| Category of reported experience | Description | Number of participants (n) | Percentage (%) |
|---|---|---|---|
| **Loss of routine and team belonging** | Statements referring to the absence of structured training schedules, competition routines, and team identity after withdrawal | 29 | 60.4 |
| **Emotional and psychological difficulties** | Reports of emotional distress, anxiety, reduced motivation, feelings of emptiness or sadness following sport dropout | 24 | 50.0 |
| **Difficulties with adaptation and identity transition** | Responses describing challenges in adjusting to post-sport life, uncertainty about personal direction, or loss of athletic identity | 19 | 39.6 |
| **Reduced physical activity levels** | Mentions of decreased exercise frequency and difficulty maintaining physical activity after leaving performance sport | 17 | 35.4 |
| **Positive life reorientation** | Responses highlighting positive outcomes such as increased focus on education, improved social life, personal development, or better life balance | 21 | 43.8 |
| **Continued recreational sport participation** | Explicit mentions of continuing basketball or other physical activity at a recreational or hobby level | 43 | 89.6 |

Analysis of the open-ended responses revealed that post-dropout experiences were multifaceted, with most participants reporting loss of routine and team belonging (60.4%), emotional or psychological difficulties (50.0%), and challenges related to adaptation and identity transition (39.6%). At the same time, a substantial proportion also identified positive reorientation outcomes (43.8%), while the majority continued engaging in basketball at a recreational level (89.6%).

## DISCUSSIONS

This study examined factors associated with withdrawal from performance-level basketball, integrating demographic characteristics, sport participation histories, psychological experiences, and post-dropout outcomes. The findings reinforce the view that sport dropout is a multifactorial process shaped by developmental, psychological, and structural influences rather than a single decisive event.

First of all, withdrawal from performance basketball occurred most frequently during late adolescence, with a mean dropout age of 17.5 years and a clear concentration at ages 17–18. This period coincides with major educational and life transitions, during which athletes face increased academic demands and decisions about future careers. Participants typically began basketball at an early age (mean = 8.91 years), indicating long-term engagement before withdrawal. Together, these findings highlight late adolescence as a critical phase for dropout risk, consistent with previous research identifying transition periods as vulnerable moments for sport disengagement (Battaglia et al., 2024; Zhang et al., 2024). Moreover, as shown in Fig. 2, the most frequently reported reasons for withdrawal were other academic opportunities and the perceived lack of opportunities to progress in performance basketball. This perception is supported by the competitive background data (Table 1), which show that most participants competed at junior or national levels, where advancement options may be limited. These findings align with evidence that conflicts between education and sport, combined with unclear development pathways, are major contributors to dropout during late adolescence (Zhang et al., 2024).

Taking into account, psychological factors played an important role in athletes' experiences. Although almost all participants recognised mental preparation as equally important as physical preparation, most reported no access to psychological support during their careers (Table 2). Many described the competitive environment as stressful and half experienced mental overload. These findings suggest a gap between athletes' psychological needs and the support structures available, which may increase vulnerability to disengagement. Similar concerns have been reported in recent research on mental health risks among young and elite athletes (Lundqvist et al., 2023).

Coach-related factors appeared to influence athletes indirectly.

As illustrated in Fig. 3, a majority of participants experienced excessive pressure from coaches, while emotional support was often perceived as partial or insufficient. Although most participants did not attribute their dropout decision solely to coaches, these findings indicate that coaching behaviours may shape the motivational climate in ways that contribute to withdrawal. This is consistent with previous studies showing that controlling or highly result-focused coaching environments can undermine motivation and well-being (Orbach et al., 2022). Injury experiences were common, with over half of participants reporting injuries that affected their careers (Fig. 4). Most also perceived recovery resources as insufficient, pointing to structural limitations within clubs or sport systems. Inadequate access to rehabilitation and medical support may increase both physical and psychological strain, contributing to dropout decisions, particularly when combined with other pressures.

Post-dropout experiences were mixed. As summarised in Table 3, many participants reported loss of routine, emotional difficulties, and challenges adapting to life after performance sport, reflecting disruptions in daily structure and athletic identity. At the same time, most participants continued to engage in basketball or other physical activities recreationally, and many reported positive outcomes such as improved life balance and personal development. These findings support the idea that reduced participation in organised sport does not always indicate negative outcomes, but may represent an adaptive transition when physical activity and well-being are maintained.

## CONCLUSIONS

Findings form this study highlights withdrawal from performance-level basketball as a multifactorial and developmentally sensitive process. Dropout occurred most frequently during late adolescence, despite early and long-term engagement with the sport, and was strongly influenced by academic demands, limited perceived opportunities for progression, and increasing psychological strain. Discussions revealed a clear mismatch between athletes' psychological needs and the support structures available, with high performance pressure, limited access to psychological support, and coaching climates perceived as emotionally demanding. Injury experiences and insufficient recovery resources further contributed to disengagement from performance basketball.

Importantly, withdrawal from performance sport did not result in complete disengagement from physical activity. Most participants continued to practice basketball recreationally and reported both challenges and positive adjustments after dropout. These results suggest that dropout should be understood not only as a negative outcome, but also as a transitional phase requiring better structural, psychological, and educational support.

## STUDY LIMITATIONS

The cross-sectional design of the study does not allow for causal inferences. Although associations between various factors and dropout were identified, it is not possible to determine the prior direction or relative weight of these influences over time.

## AUTHORS CONTRIBUTIONS

Ildiko Manasses and Claudiu-Adrian Pașcan contributed to the conceptualization, design of the study and initial drafting of the manuscript. Denisa-Annamária Kis contributed to the data collection, literature review and writing of the manuscript. Paula-Alina Apostu and Maria-Daniela Macra-Oșorhean contributed to the methodological design, data analysis, interpretation of results and also scientific supervision. 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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# Study on the Level of Motor Control and Proprioception Among Folk Dance Athletes

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**ABSTRACT**. **Introduction:** Dance is a complex physical activity that integrates motor, cognitive, emotional, and social components. Through repetitive, rhythmical, and coordinated movements, dance contributes to the development of motor control, proprioception, balance, and overall psychomotor abilities. In childhood, these components are essential for harmonious physical and mental development. **Objectives:** This study aimed to investigate whether children who practice folk dance demonstrate higher levels of motor control and proprioception than children who do not participate in any sport, by comparing static and dynamic balance, as well as reaction time, between the two groups. **Methods:** A prospective study was conducted on 69 children aged 7-12 years, divided into an experimental group (34 folk dancers) and a control group (35 non-sport practitioners). The assessment included the Standing Stork Test for static balance, the Modified Bass Test for dynamic balance, and the Reaction Time Test. **Results:** The experimental group achieved significantly better results in both balance tests. In the Standing Stork Test, a statistically significant difference was observed between groups (p = 0.041), favouring folk dancers. The Modified Bass Test also showed a significant difference (p = 0.001), indicating superior dynamic balance in the experimental group. Although reaction time values were

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slightly better in dancers, no statistically significant differences were found between groups in either reaction time test ($p > 0.05$). **Conclusions:** The findings suggest that children who practice folk dance exhibit higher levels of motor control and proprioception, particularly in static and dynamic balance, compared with non-sport-practising peers. While reaction time did not show significant differences, the overall results support the role of folk dance as an effective activity for enhancing motor control and proprioceptive abilities in children.

***Keywords:*** *folk dance, motor control, proprioception, balance, children, psychomotricity.*

## INTRODUCTION

Dance is recognised as an effective means of improving physical fitness, fostering social skills, and enhancing mental health; it can be initiated early in life and continues to provide entertainment into older adulthood (Malkogeorgos et al., 2011). The specific qualities and benefits of dance vary by form, but generally, dance enhances physical health by developing strength, flexibility, coordination, and balance. Mental health benefits are attributed to increased self-esteem resulting from movement to music, cooperation with others, and the formation of new social connections (Bremer, 2007). Participation in dance activities supports the development of skills in recognising, differentiating, and executing rhythmic structures, dynamics, tempo, spatial orientation, and control. Various forms of dance contribute positively to coordination between the arms and legs, as well as overall body coordination (Cavallo, 2021). Folk dance, in particular, significantly influences the acquisition of complex motor tasks, reorganisation of movement patterns, rhythmic coordination, precision, and balance (Markovic et al., 2023).

Motor control is the ability to regulate the mechanisms essential to movement (Shumway-Cook & Woollacott, 2007). In Motor Control: Integrating Research into Clinical Practice, Shumway-Cook and Woollacott describe an integrated theory of motor control that reflects key elements of hierarchical, systems, dynamic action, and ecological theories. This integrated systems-based theory conceptualises movement as a product of the interaction between the individual, the task, and the environment. Shumway-Cook and Woollacott's theory, which views movement as produced by a person to satisfy the needs of a particular activity in a particular environment, echoes many ideas of other systems-based theories (Kenyon & Blackinton, 2011).

Every movement, from involuntary to goal-directed, in every body part, from head to toe, in every physical and social context—from solitary play to group interactions—is included in motor control. From the first fetal movement to the final breath, motor behaviour develops throughout a person's life (Adolph &

Franchak, 2017). Although movements fundamentally depend on the generation, control, and exploitation of physical forces, managing forces requires more than muscles and biomechanics. At every stage of development, adaptive control of movement relies on basic psychological functions (Bernstein, 1996). Perception and cognition are necessary for planning and guiding actions (Keen, 2011). Social and cultural factors stimulate and constrain motor behaviours (Adolph et al., 2010). Motor behaviours, in turn, provide the raw material for perception, cognition, and social interaction (Gibson, 1988; Piaget, 1954). Movements generate perceptual information, provide a means of acquiring knowledge about the world, and enable social interactions. Proprioception refers to the sense of body position and movement. In addition to the senses of position and movement, it includes the sense of effort, force, and weight. In order to enhance or restore sensorimotor function, proprioceptive training is an intervention (Aman et al., 2015; Winter et al., 2022).

Humans have a multitude of senses, including sight, hearing, smell, taste, and somatosensory perception, which are traditionally described as the five senses. In the 19th century, Scottish anatomist Sir Charles Bell first characterised the “muscle sense” as the sixth sense (Singh, 1991; Dickson et al., 2000; Bell, 1834). In the early 20th century, Charles Scott Sherrington studied the peripheral sources of sensory input and their control over muscle contraction, and introduced the terms “exteroception”, “interoception”, and “proprioception” (Sherrington, 1906; Sherrington, 1913). Exteroception detects environmental stimuli from outside the body, while interoception detects internal states or signals from internal organs. Proprioception detects the movements of our body, including those of our limbs and muscles (Moon, 2021).

According to Riemann and Lephart (2021), proprioception encompasses proprioceptive information used by the higher nervous system to produce sensations of limb and body position and movement. Mechanoreceptors are specialised sensory receptors that transduce mechanical stimuli into neural signals and provide proprioceptive information. They are mainly found in muscles, tendons, ligaments, capsules, and skin. Proprioceptive information is transmitted to the central nervous system for processing and, ultimately, the regulation of reflexes and motor control results (Hewett et al., 2002).

The proprioceptive system, in general, allows the proper functioning of the locomotor apparatus during movement and sports activities, maintains muscle tone, and helps us accurately differentiate isolated body movements, which are particularly attractive in choreographed dancers (Ljubojević et al., 2020).

Developing an understanding of proprioception and implementing targeted proprioceptive training within physical conditioning for dance sport may improve body awareness, enhance dance performance, and reduce the risk of injury (Batson, 2009). Employing such training methods can facilitate meeting the aesthetic and physical demands of dance sport. Furthermore, minimising injury risk may contribute to the longevity of a dancer's career (Ljubojević et al., 2020).

Psychomotricity is a cross-disciplinary field of study, drawing on disciplines that define the complexity of the processes underlying the meaning of various human bodily manifestations, contextualised within movement, integration, and the individual's relationship with their extremely diverse environment.

The term "balance" refers to a type of coordination of motor movements in which the visual and kinesthetic components of the body's muscles work together with balance sensors in the middle ear to maintain stability without unnecessary movement or falls (Goddard, 2017).

The body's ability to balance depends on internal systems, such as the vestibular system (balance sensors), the proprioceptive system (motion sensors), and the visual system. Balance also depends on external factors, such as the base of support, the centre of gravity, and the body's structure and weight (Davlin, 2004).

Several external and internal factors influence an individual's ability to maintain balance, including genetics, age, support zone, centre-of-mass positioning, emotional state, strength, coordination, flexibility, frequency of motor activity participation, and fitness level. Regardless of these factors, static and dynamic balance remain indispensable motor skills, as they lie at the heart of all human movements (Stanković & Radenković, 2002).

In the field of locomotion, the ability of bipedal creatures to stabilise themselves is crucial and requires them to be perpendicular to their centre of gravity and their support zone, i.e., to stand on their feet and the area between their legs. The transition from standing on one leg to the other requires a forward movement with a narrow base, while maintaining stability and activating the balance system as part of the posture (Hof, 2008). In addition, basic movements such as running, changing direction, stopping, and advancing on elevated surfaces require the person to maintain stability and require training to develop the balance system (Haddad et al., 2013).

The term dynamic balance refers to the ability to maintain the centre of gravity above the base of support during movement, even as the body moves away from it. In dynamic balance, the primary process is the coordination between maintaining the trunk above the centre of gravity and various forward movements, which enables stability and reflex responses to changes in movement. To successfully maintain dynamic balance, one must be prepared with responses to expected changes (Hatzitaki et al., 2002). Dynamic balance is part of any progression skill and manifests itself at the moment of transition from base to base, when there is a detachment of a moving body part from the ground. Examples of detachment are walking, running, jumping, and landing (Yanovich & Bar-Shalom, 2022).

In activities such as dance, dynamic balance is essential for accurate movement execution and injury prevention. Dancers are required to rapidly shift their centre of gravity while maintaining stability during complex movements.

Among the many activities, dance is cited as one that improves balance (Davlin, 2004). As we know, postural balance is an important component skill for dancers (Steinberg et al., 2018). Dance performance is a complex act that involves many elements, including strength, balance, flexibility, and endurance (Janura et al., 2019). Data show that dancers' skill depends largely on practical technical training, with elements of good posture and balance, and requires the encoding of sensory inputs to build mental representations of the action to be performed (Yanovich & Bar-Shalom, 2022; Hugel et al., 1999).

The human ability to coordinate our movements plays a role in dozens of everyday contexts, allowing us to plan and perform motor tasks ranging from walking to dancing. Coordination has been defined as the organisation of degrees of freedom within a motor system in relation to one another (Black, 2007; Hartmann et al., 2019).

Hand-eye coordination is the ability of the central nervous system to integrate visual information to control, guide, and direct the hands during a given task (Wong et al., 2019; Pepper, 1984).

In recent years, various forms of dance have been widely promoted in the professional press and have attracted considerable attention in the medical literature. This trend aligns with increased awareness of physical fitness, driven by accumulating evidence linking cardiovascular disease to physical inactivity, reduced cardiopulmonary fitness, and obesity. Multiple authors have proposed that dance is a viable alternative to traditional physical exercise for modifying sedentary behaviour and maintaining fitness and optimal body weight (Hanna, 1995).

Dance engages the body, emotions, and mind, paralleling the multifaceted nature of illness and pain. Participation in dance may promote well-being by strengthening the immune system through muscular activity and physiological processes. Additionally, dance can help individuals moderate, eliminate, or avoid tension, chronic fatigue, and other stress-related conditions (Verhaar et al., 2022).

From a physical and physiological perspective, childhood marks the most important stage of development, during which personality is formed (Melguizo-Ibanez et al., 2022). The influence of the growing environment and the activities carried out is crucial for the physical and mental development of children, and emotional control plays an essential role in the formation of a healthy lifestyle from a cognitive (subjective), behavioural (expressive), and psychological (adaptive) point of view (Vasilopoulos, 2023).

The use of dance and folk dances in early school-age plays a crucial role in the development of motor skills and the general psychophysical development of children in this age group (Tortora, 2006).

Children's free expression through spontaneous dance is an intrinsic part of childhood. As a child explores the world, actively engaging with it physically, a sense of self and empowerment in it develops (Faber, 2016).

The earlier dance education begins, the greater the chances of developing intelligence. Brain activity is significant in children, and this sport has a positive impact on mental, emotional, and social well-being from the first years of life, with forms of communication during this period based on gestures and movements (Karpati et al., 2016).

Compared to people who practice other physical and leisure activities, dancers and musicians have a greater ability to distinguish sounds, understand information, anticipate and imitate the following movements of people around them or other living organisms, feel the rhythm and synchronise movements with music, orient themselves in space and time and control their posture (Tomescu et al., 2023; Epuran & Stănescu, 2010).

*The purpose of this study was to determine whether dance athletes exhibit higher levels of motor control and proprioception compared to non-athletes, as assessed by static and dynamic balance and reaction time.*

*The hypothesis posits that regular dance rehearsals positively influence the development of motor control and proprioception in dancers compared to non-dancers.*

## MATERIAL AND METHOD

### Participants

Participants included 69 children aged 7–12 years, divided into two groups: an experimental group of 34 children who practised folk dance and a control group of 35 children who did not participate in sports activities.

Inclusion criteria were: age between 7 and 12 years and active participation in the Zsurló folk dance group. The control group consisted of students from "Aurel Mosora" Secondary School in Sighișoara who did not practice sports.

The study was approved by the Ethics Committee of the "George Emil Palade" University of Medicine, Pharmacy, Science and Technology of Târgu Mureș (Approval no. 2760, 2024). The research respected the Declaration of Helsinki (2013) and the General Data Protection Regulation (EU) 2016/679.

**Procedure**

The assessment included three tests:

- Standing Stork Test for static balance
- Modified Bass Test for dynamic balance
- Reaction Time Test (CPS Check) for hand-eye coordination

Invalid attempts in the reaction test were excluded from analysis. Final samples were:

- 69 subjects for balance tests
- 66 subjects for Reaction Time Test 1
- 67 subjects for Reaction Time Test 2

The prospective study was conducted using the bibliographic study method, non-participant observation, measurement and recording through standardised tests, and graphical presentation of results.

This topic was selected to provide a significant contribution to understanding the influence of folk dancing on the development of motor and sensory skills in children. The findings may inform the implementation of educational and sports programs and promote the benefits of dance by integrating physical education and psychomotor education.

The tests administered included the Standing Stork Test, the Modified Bass Test, and the Reaction Time Test (CPS-Check).

***The Standing Stork Test*** assesses static balance

The test requires the participant to stand on one leg for up to 60 seconds on a flat surface. Following a brief warm-up, the participant lifts one leg and places it on the supporting leg's knee, with both hands on the hips. The objective is to maintain the raised-and-flexed-leg position for as long as possible. Timing begins once the correct position is achieved and ends when the raised leg touches the ground or after 60 seconds. If the participant is unable to maintain the position for the full duration, the elapsed time is recorded. A stopwatch is used for timing.

***The Modified Bass Test*** evaluates dynamic balance

The participant is required to walk a designated route without losing balance. The test begins with the participant standing on one leg, with the left lower limb on the paper marked "Start." The participant then jumps onto the paper labelled "1" with the right lower limb and remains stationary. After five seconds, upon the examiner's signal, the participant proceeds to the paper labelled "2" with the left lower limb. This sequence continues until reaching the final paper labelled "10," where the test concludes with the participant standing on the left lower limb.

Scoring is based on awarding five points for each correct landing, defined as the entire foot placed stably on the paper, and one point for each second the participant maintains balance on one leg. The maximum possible score is 100 points. The examiner records each landing and the duration spent balanced on each paper. Materials required include paper, adhesive tape, and a stopwatch.

***The Reaction Time Test is*** an online assessment designed to evaluate hand-eye coordination. Upon accessing the application, participants are prompted to click to initiate the test. After clicking, the image changes, and participants must wait until the screen turns green before clicking again as quickly as possible. The application records reaction time in milliseconds. If a participant clicks before the screen turns green, the screen turns red, and the attempt is invalidated. Each participant completes two trials, and both results are recorded. Testing is conducted using a mouse. Invalid attempts are not repeated. Materials used include a laptop and a mouse.

### Data analysis

Descriptive statistics were calculated, including the mean, median, standard deviation, minimum, and maximum. The Anderson-Darling test was used to assess the normality of data distribution. For comparison between groups, the independent-samples Student's t-test was used. The level of statistical significance was set at $p < 0.05$. All analyses were performed using Minitab software (version 20.3, Minitab LLC, 2021).

## RESULTS

In total, we tested 69 subjects: 39 females and 30 males. We juxtaposed their results by comparing the average and minimum/maximum values, the results relative to the average in each test, and the number of disabilities in the Reaction Time Test.

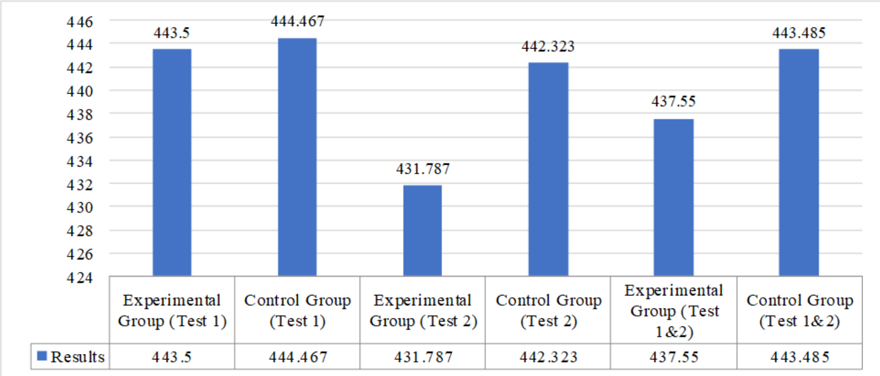



**Fig. 1.** Comparison between the average results, The Reaction Time Test (UM=ms)

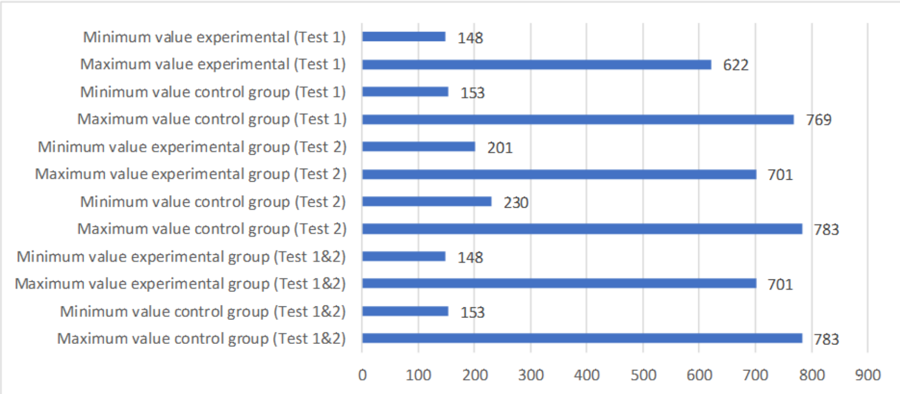



**Fig. 2.** Comparison of extreme values, The Reaction Time Test (UM=ms)

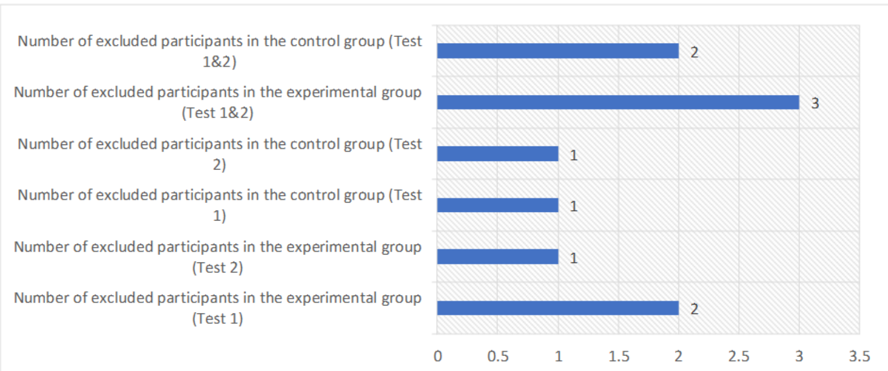
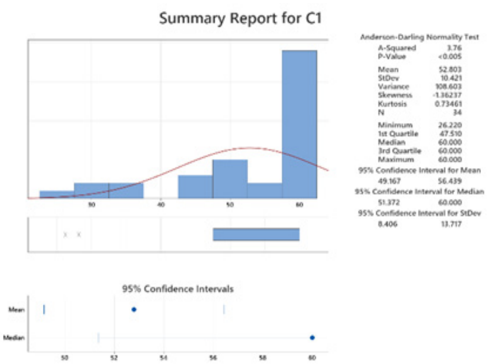



**Fig. 3.** Number of disabilities, The Reaction Time Test

Descriptive and inferential statistics, including the median, mean, and standard deviation, were used in the analysis. The Anderson-Darling normality test assessed the data's conformity to a normal distribution. The Student's t-test for unpaired data was employed to compare means. Statistical analyses were conducted using Minitab (Minitab 20.3, LLC, 2021).

**Table 1.** Analysis of the Standing Stork test

| | Experimental group - EG | Control Group - CG |
|---|---|---|
| Average | 52.8 | 46.7 |
| Minimum | 26.2 | 11.6 |
| Median | 60 | 60 |
| Maximum | 60 | 60 |
| | p=0.041 | |



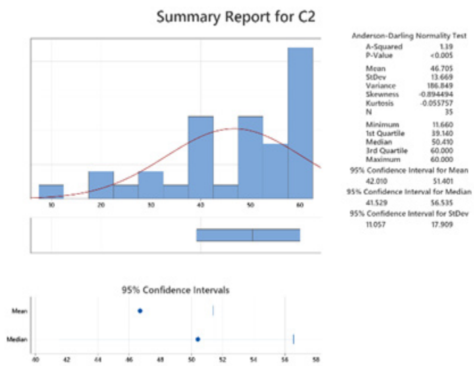




**Fig. 4.** Normality test AD Experimental Group **Fig. 5**. Normality test AD Control Group

Anderson-Darling test, p<0.05: there is a statistically significant difference between the median values of the two groups.

**Table 2.** Modified Bass Test Analysis

| | Experimental group - EG | Control Group - CG |
|---|---|---|
| Average | 92.8 | 85.8 |
| Std Deviation | 6.6 | 7.5 |
| T-Test | p=0.001 | |

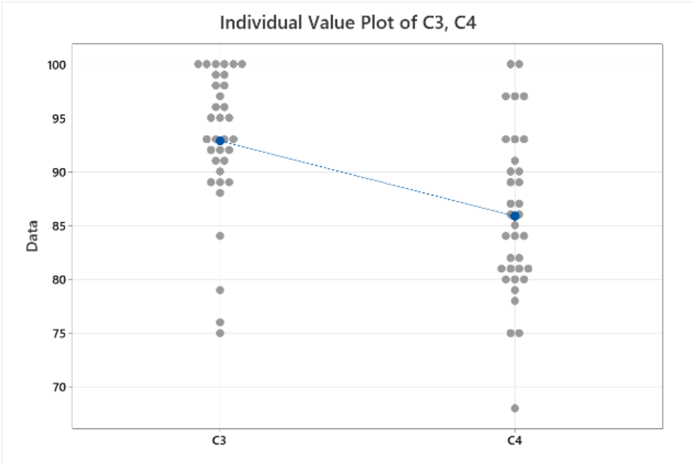



**Fig. 6.** Outlier analysis GE., GC., Modified Bass test (C3-GE, C4-GC)

Student's T-test, $p<0.05$: there is a statistically significant difference between the median values of the two groups.

**Table 3.** Analysis of the Reaction Time Test 1

| | Experimental group - EG | Control Group - CG |
|---|---|---|
| Average | 444 | 445 |
| Std Deviation | 114 | 143 |
| T-Test | p=0.971 | |

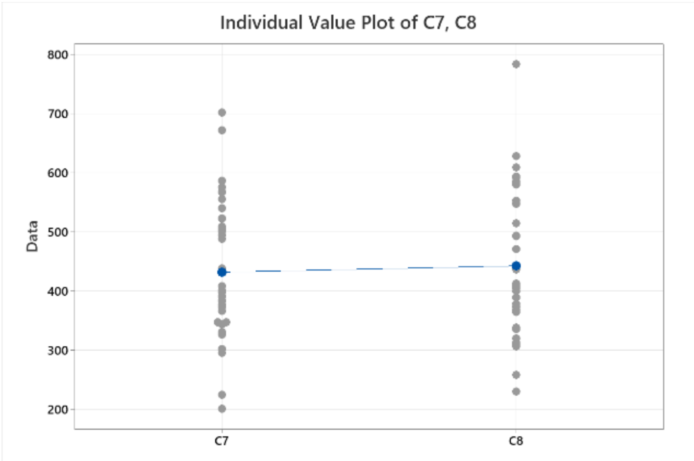



**Fig. 7.** Outlier analysis GE., GC. The Reaction Time Test 1 (C5-GE, C6-GC)

Student's T-test, p>0.05: there is no statistically significant difference between the medians of the two groups.

**Table 4.** Analysis of the Reaction Time Test 2

| | Experimental group - EG | Control Group - CG |
|---|---|---|
| Average | 432 | 442 |
| Std Deviation | 118 | 128 |
| T-Test | p=0.727 | |

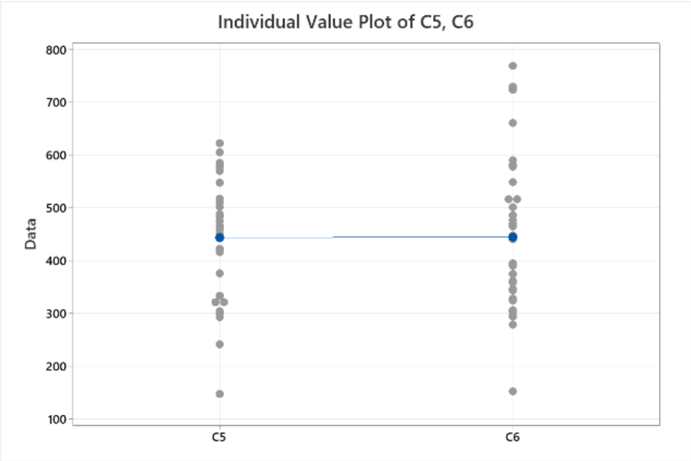



**Fig. 8.** Outlier analysis GE., GC.. The Reaction Time Test 2 (C7-GE, C8-GC)

Student's T-test, p>0.05: there is no statistically significant difference between the medians of the two groups.

## DISCUSSIONS

This study indicates that children who participate in folk dance demonstrate better motor control and proprioception than non-dancers, as evidenced by improved static and dynamic balance and quicker reaction times. These findings align with existing research that connects dance training to gains in strength, coordination, postural control, and multisensory integration. Regular rehearsals likely improve sensory encoding in the visual, vestibular, and proprioceptive systems, thereby supporting internal models for anticipatory and reactive movement adjustments. Improved balance and hand-eye coordination in dancers may reduce injury risk, extend active participation, and inform the development of school- and community-based programs focused on psychomotor skills.

As shown in the results above, the subjects practising folk dance performed better on each test than the control group. In the Standing Stork test, the experimental group had an average of 6.098 seconds higher than the control group. Analysing the maximum value, there were no differences, but the minimum value was 14.56 seconds lower in the control group than in the experimental group. Another result that did not show significant differences is the number of subjects who obtained a value higher than the group average. In both groups, approximately 60% of participants exceeded the average, while approximately 40% fell below it. Schell and Leelarthaepin (1994) presented a table of results from this test (Table 2). Based on this table, the experimental group has 1 subject at the average level, while the control group has 2 at the average level and 1 at the below-average level.

**Table 4.** Standing Stork test classification, according to Schell and Leelarthaepin (UM=s)

| | Excelent | Above Average | Average | Below average | Poor |
|---|---|---|---|---|---|
| M | >50 | 37-50 | 15-36 | 5-14 | <5 |
| F | >27 | 23-27 | 8-22 | 3-7 | <3 |

Looking at other literature studies, we can see both similarities and discrepancies. A 2011 study shows that dance improved static balance in children playing soccer, while other research reported no significant improvements in children's balance due to dance (Ricotti & Ravaschio, 2011; Chatzopoulos et al., 2018).

In the Modified Bass test, which assesses dynamic balance, the experimental group also performs better. The difference between the two sample means is 7 points. As observed in the above test, the maximum value is the same in both groups, and the difference between the minimum values in the control and experimental groups is also 7 points, in favour of the latter. Another factor supporting the idea that dancing children have a higher level of dynamic balance is the distribution of the subjects relative to the mean of the results. 59% of subjects in the experimental group exceeded the sample mean, whereas only 49% in the control group did so. However, some studies criticise this test, stating that it seemed too easy to administer to their subject population (Tsigilis et al., 2001). Also, in 2011, other research failed to show differences in balance between active dancers and non-dancers using this test (Ambegaonkar, 2011).

The Reaction Time Test also showed superior results in the experimental group, though the differences were less pronounced. The average value of the four tests showed a difference of only 6 milliseconds. The extreme values did not differ significantly either, or, in terms of disabilities, there were three in the experimental group compared to two in the control group. The study conducted by Quiroga Murcia and his collaborators in 2010 investigated the benefits of dance on health and well-being, including reaction time in children. The study found that subjects who practiced dance showed significant improvements in reaction time compared with those in the control group (Quiroga et al., 2010). Similar conclusions were reached by Kattenstroth et al. (2013) following a 6-month study analysing the reaction time of subjects who practiced dance for 1 hour per week.

The results of this study show that preschool children who practice folk dance have higher levels of static and dynamic balance, but it cannot be stated with certainty that practicing dance would directly improve hand-eye coordination. For the latter, more specialised studies are needed to prove it.

However, despite the lack of significant differences in reaction time, the results from the other tests confirm the hypothesis that regular dance practice improves motor control and proprioception.

Thus, we can, with evidence, suggest integrating folk dance into school physical education programs, and children's reactions and attitudes confirm that they would be open to such a change.

### Strengths and Limitations of the Study and Future Research Directions

The strengths of this study include the use of standardised field tests and a real-world sample; however, several limitations should be considered. The modest sample size, restricted age range, and cross-sectional design limit generalizability and preclude causal inference. Reliance on clinical tests and an online reaction task may introduce practice effects and may lack the sensitivity of instrumented measures. Future research should employ longitudinal or randomised interventions, recruit larger and more diverse cohorts, utilise wearable or laboratory-based assessments of proprioception and balance, and investigate dose–response relationships and functional outcomes. Despite these limitations, the findings support integrating folk dance into childhood physical education to enhance motor skills, sensorimotor integration, and broader health-related outcomes.

## CONCLUSIONS

In conclusion, the results indicate that athletes who practice folk dance demonstrate higher motor control and proprioception than those who do not participate in sports. Early education in folk dance supports both physical and mental health. This and other research confirm that balance improves through movement, and folk dance offers distinct advantages in this area.

## AUTHOR CONTRIBUTIONS

All authors contributed to the study design, data collection, analysis, and manuscript writing. All authors approved the final version.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.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# The Effect of Dynamic Games on the Harmonious Physical Development of Primary Students

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**ABSTRACT.** In the context of a modern society, where the health of the population is affected by a sedentary lifestyle, the harmonious physical development of children becomes an essential priority. Physical development represents both the result and the process aimed at ensuring a healthy and balanced growth of the body, expressed through proportional morphological and functional indicators, which are as close as possible to the values considered normal for a healthy body**. Research hypotheses**. 1. Regular implementation of dynamic games in "Play and Movement" lessons contributes to harmonious physical development, highlighted by the increase in the corresponding somatic indices of primary school students; 2. Active participation in dynamic games in "Play and Movement" lessons determines the improvement of motor qualities, highlighted by the increase in the indices of speed, strength and skill of primary school students. **Methods and means**. For this research, primary school students from the "Mihai Viteazul" Secondary School in Câmpia Turzii participated**.** The working sample consisted of 55 students (24 boys and 31 girls), who were subjected to motor measurements and testing in two stages during the 2024-2025 school year. For the measurements of motor qualities, a battery of tests was used: 5x5m shuttle, Matorin test, standing long jump. All statistical analyses were performed using the SPSS Statistics program with a significance level of 5%**.** Data distribution was verified using the Shapiro-Wilk test, and means were compared using tests based on distribution. **Results**. The average time decreased significantly for both groups (boys and girls) in the 5x5m shuttle, indicating an

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improvement in speed and effort capacity. A significant increase in the distance in the standing long jump was observed in both groups (p <0.001), signaling a development of muscle strength. Significant improvement was present in both groups, indicating a positive evolution in terms of coordination and general balance through the Matorin test. **Conclusion.** Dynamic games are a valuable teaching strategy, effective both in developing motor skills and in supporting balanced and attractive physical development for young school-age children.

***Keywords****: dynamic games, harmonious physical development, primary school, play and movement*

## INTRODUCTION

In the context of modern society, where public health is increasingly affected by sedentary lifestyles, fostering the harmonious physical development of children has become a fundamental priority. The subject "*Play and Movement*", designed for primary school pupils, plays a significant role in this process by contributing to the formation of healthy habits and the adoption of an active lifestyle.

The curriculum of "*Play and Movement*" is structured according to an innovative curricular design model, with competencies at its core. Its aim is to support the development of the educational profile of primary school pupils (Balint, 2009). From the perspective of this subject, a competence-based approach allows for a stronger emphasis on the practical dimension in shaping pupils' personalities.

Through "*Play and Movement*", a similar objective is pursued to that of physical education lessons: engaging pupils in activities that channel their energy constructively, preventing its diversion toward violent behaviors. The organization of motor activities contributes to the establishment of healthy social habits and to the balanced development of personality (Dragnea et al., 2006).

Physical development represents both the outcome and the process directed toward ensuring a healthy and balanced growth of the organism, expressed through proportional morphological and functional indicators that approximate the values considered normal for a healthy body.

This involves two main categories of indicators (Cârstea, 2002):

- **Somatic/morphological indicators**, which can be directly observed or measured, such as height, weight, body segment dimensions, perimeters, and diameters.

- **Functional/physiological indicators**, which are not visible to the naked eye but constitute the organism's functional foundation and are assessed through measurements such as pulse, respiration, respiratory capacity, and blood pressure.

Growth and development are influenced both by genetic factors (heredity) and by external factors (environment, living conditions, nutrition). Somatic development determines increases in body mass, as well as the evolution of tissue and organ structure and functionality. Physical activity plays a crucial role in this process by stimulating the locomotor system, respiration, and blood circulation (Bompa, 2001).

Dynamic games represent engaging activities with a predominantly motor structure, involving constant interaction among participants (Scarlat, E. & Scarlat, B., 2006; Stănescu, 2012). They stimulate teamwork, initiative, and active participation, serving as an effective means of developing motor abilities (Neacșu et al., 2010).

At younger grade levels, emphasis should be placed on consolidating correct execution rather than on speed-oriented competitions, in order to reduce the risk of injury. Dynamic games should be frequently diversified to ensure pupils' comprehensive and varied development (Rață, G. & Rață, B., 2006). Coordination exercises included in dynamic games contribute to the development of balance, courage, self-control, attention, reflexes, and spatial perception, while also strengthening skills that are useful in everyday life (Cristea et al., 2002; Cârstea, 2000).

### Research Hypothesis

1. The regular implementation of dynamic games within "Play and Movement" lessons contributes to a harmonious physical development, as evidenced by improvements in the somatic indices appropriate to pupils in primary education;
2. Active participation in dynamic games during "Play and Movement" lessons leads to enhanced motor abilities, as reflected in increased levels of speed, strength, and coordination among pupils in primary education.

### Research objectives

1. To evaluate the impact of dynamic games on the harmonious physical development of pupils in primary education by measuring and analyzing changes in somatic indicators (weight, height, and body mass index – BMI);
2. To analyze the influence of dynamic games on the improvement of motor skills (speed, coordination, and strength) among pupils in primary school.

## MATERIAL AND METHODS

For this research, pupils from the primary education cycle at "*Mihai Viteazul*" Gymnasium School in Câmpia Turzii participated. The working sample consisted of 55 pupils (24 boys and 31 girls), who were subjected to anthropometric measurements and motor ability testing in two stages: Stage I – October 2024, and Stage II – February 2025. During this period, pupils followed the regular "*Play and Movement*" program, in accordance with the requirements of the official curriculum tailored to their age. All lesson objectives and topics were addressed through the use of dynamic games.

The "*Play and Movement*" lessons were conducted in the school gymnasium of "*Mihai Viteazul*" Gymnasium School in Câmpia Turzii, once per week, with each session lasting 50 minutes. The intervention program consisted of the systematic implementation of dynamic games, selected by the teacher according to the specific themes and objectives pursued.

### Research instruments

Anthropometric measurements were carried out in the school's medical office, using a scale (for measuring body weight) and a stadiometer (for measuring height).

For the assessment of motor abilities, a battery of tests was applied, including: the 5x5 m shuttle run, the Matorin test, and the standing long jump.

**Fig. 1.** Shuttle run 5x5m

**Fig. 2.** Standing long jump

### Statistical Analysis

All statistical analyses were performed using SPSS Statistics (v.17; SPSS, Inc., Chicago, IL) with a significance level set at 5% (p < .05 considered statistically significant). The distribution of the data was verified using the Shapiro–Wilk test, and the means were compared by applying appropriate tests according to the distribution.

## RESULTS

Following the collection and processing of the data obtained from the conducted measurements, the results were analyzed according to the two measurement stages (M1 and M2). To compare the means between these two stages, the paired-samples *t*-test was applied, as the data were normally distributed.

**Table 1.** Comparison of means for the Shuttle Run, Long Jump, Matorin Test for M1 and M2

| Paired Samples Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | N | Mean | Std. Deviation | Mean | t | df | Sig. (2-tailed) |
| **Pair 1** | **SR_B_M2** | 24 | 12.13 | 1.16 | -0.69 | -17.681 | 23 | .000 |
| | **SR_B_M1** | 24 | 12.82 | 1.17 | | | | |
| **Pair 2** | **Jump_B_M2** | 24 | 157.54 | 13.09 | 9.73 | 17.262 | 23 | .000 |
| | **Jump_B_M1** | 24 | 147.81 | 12.20 | | | | |
| **Pair 3** | **Matorin_B_M2** | 24 | 22.57 | 3.90 | -1.96 | -16.341 | 23 | .000 |
| | **Matorin_B_M1** | 24 | 24.53 | 3.75 | | | | |
| **Pair 4** | **SR_G_M2** | 31 | 12.32 | 1.17 | -0.59 | -20.718 | 30 | .000 |
| | **SR_G_M1** | 31 | 12.91 | 1.12 | | | | |
| **Pair 5** | **Jump_G_M2** | 31 | 162.97 | 11.11 | 7.60 | 18.867 | 30 | .000 |
| | **Jump_G_M1** | 31 | 155.37 | 11.53 | | | | |
| **Pair 6** | **Matorin_G_M2** | 31 | 22.98 | 5.76 | -1.56 | -15.761 | 30 | .000 |
| | **Matorin_G_M1** | 31 | 24.54 | 5.87 | | | | |

The data in Table 1 show significant progress across all motor ability tests for both boys and girls.

- **5x5 m Shuttle Run (Speed):**

Boys improved their average time from 12.82s (SD=1.17) at M1 to 12.13s (SD=1.16) at M2 (t = -17.681; $p < 0.001$).Girls also recorder a significant decrease, from 12.91s (SD=1.12) to 12.32s (SD=1.17; t = -20.718; $p < 0.001$).

These findings indicate a marked improvement in speed and effort capacity in both groups.

- **Standing Long Jump:**

Boys increased their average performance from 147.81cm (SD=12.20) to 157.54cm (SD=13.09; t = 17.262; $p < 0.001$). Girls showed similar progress, from 155.37cm (SD-11.53) to 162.97cm (SD=11.11; t = 18.867; $p < 0.001$). The results confirm the efficiency of dynamic games in developing muscular strength.

- **Matorin Test:**

Boys improved from $24.53^0$ (SD=3.75) at M1 to $22.57^0$ (SD=3.90) at M2 (t = -16.341; $p < 0.001$). Girls recorded an increase from $24.54^0$ (SD=5.87) to $22.98^0$ (SD=5.76; t = -15.761; $p < 0.001$). These results demonstrate a significant enhancement in coordination and balance, confirming the contribution of dynamic games to motor skill development.

The overall improvements across all three tests validate the initial hypothesis that dynamic games significantly enhance pupils` speed, strength and coordination in primary education.

**Table 2.** Comparison of means for the variables Weight, Height, BMI for MI and M2

| Paired Sample t test | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | N | Mean | Std. Deviation | Mean difference | t | df | Sig. (2-tailed) |
| **Pair 1** | **Weight_B_M2** | 24 | 38.63 | 5.61 | -0.25 | -.239 | 23 | .813 |
| | **Weight_B_M1** | 24 | 38.88 | 5.90 | | | | |
| **Pair 2** | **Weight_G_M2** | 31 | 36.45 | 5.14 | 1.00 | 12.450 | 30 | .000 |
| | **Weight_G_M1** | 31 | 35.45 | 5.35 | | | | |
| **Pair 3** | **Height_B_M2** | 24 | 144.92 | 5.16 | 2.29 | 2.676 | 23 | .014 |
| | **Height_B_M1** | 24 | 142.63 | 4.44 | | | | |
| **Pair 4** | **Height_G_M2** | 31 | 142.81 | 5.83 | 2.61 | 29.382 | 30 | .000 |
| | **Height_G_M1** | 31 | 140.19 | 6.05 | | | | |
| **Pair 5** | **BMI_B_M2** | 24 | 18.33 | 2.00 | -0.74 | -1.516 | 23 | .143 |
| | **BMI_B_M1** | 24 | 19.07 | 2.55 | | | | |
| **Pair 6** | **BMI_G_M2** | 31 | 17.79 | 1.69 | -0.16 | -3.613 | 30 | .001 |
| | **BMI_G_M1** | 31 | 17.95 | 1.84 | | | | |

The anthropometric data presented in Table 2 reflect both natural biological growth and the influence of physical activity during the intervention.

- **Weight:**

Boys` weight values remained stable between M1 (38.88kg) and M2 (38.63kg; $p$ = 0.813), suggesting a balanced growth process. In contrast, girls recorded a significant increase, from 35.45kg to 36.45kg (t = 12.450; $p < 0.001$), which may be associated with a faster biological maturation specific to this age.

- **Height:**

Both groups showed a statistically significant increase in height. Boys grew from 142.63cm (SD=4.44) at M1 to 144.92cm (SD=5.16) at M2 (t = 2.676; $p < 0.014$), while girls increased from 140.19cm (SD=6.05) to 142.81cm (SD=5.83; t = 29.382; $p < 0.001$). These values confirm normal developmental processes consistent with primary school age.

- **Body Mass Index (BMI):**

Boys recorded a decrease from 19.07 (SD=2.55) to 18.33 (SD=2.00) but, this was not statistically significant ($p$ = 0.143). Girls showed a small yet statistically significant decrease from 17.95 (SD = 1.84) to 17.79 (SD=1.69; t = -3.613; $p$ = 0.001). These results suggest that dynamic games contributed to maintaining a balanced body composition, especially among girls.

The anthropometric results confirm that pupils experienced harmonious physical development during the intervention, with height increases reflecting natural biological growth and BMI values indicating healthy balance between weight and stature.

## DISCUSSIONS

The results obtained from the application of the dynamic games program to primary school students largely confirm the hypotheses initially formulated and support the idea that these activities contribute both to harmonious physical development and to the formation of essential motor skills.

Regarding anthropometric parameters, the data revealed a significant increase in height in both groups, which is consistent with the normal growth process specific to this age. Interestingly, only girls recorded a significand increase in weight, which may be attributed to a more accelerated pace of biological maturation during this period. BMI values remained within normal limits, reflecting a balance between weight and height, and indicating a harmonious development. These findings are consistent with those reported by Lubans et al. (2010), who emphasize that regular participation in structured physical activities contributes to maintaining a healthy body composition and supports overall physical development in children. At the same time, the present results are in agreement with national studies, such as (Sopa, 2017; Hora, 2023), which highlight the role of motor activities – especially those based on play – in regulating both physical and psychomotor development in students.

The results related to motor development (speed, strength and coordination) show clear progress in both groups of students, directly confirming the effectiveness of dynamic games as a teaching method. These findings are consistent with the conclusions of Logan et al. (2012), whose meta-analysis demonstrates that structured motor interventions lead to significant improvements in fundamental movements skills in children. Similarly, Robynson et al. (2015) underline that the development of motor competence at early ages is strongly associated with improved physical fitness and increased engagement in physical activity. From a national perspective, these results also support the conclusions of Milcu (2017), who states that dynamic games are among the most effective methods for simultaneously developing motor qualities and personality traits.

Another important aspect observed in this study is the reduction of initial differences between boys and girls in certain motor performance. This finding suggests that dynamic games create an inclusive and balanced learning environment, offering equal development opportunities regardless of gender. This perspective is supported by (Pesce et al., 2013; Barnett et al., 2016), who show that well-structured physical activity programs can reduce disparities in motor competence among children.

Therefore, the present study confirms both national and international perspectives, emphasizing that dynamic games contribute not only to motor development but also to the formation of a balanced, active, and socially integrated lifestyle. Their use in primary education proves to be an effective, accessible, and attractive strategy, aligned with the current demands of modern education and with children's real needs for movement, interaction, and personal development.

## CONCLUSIONS

The study clearly highlights that the integration of dynamic games represents an effective approach to supporting the harmonious development of primary school students. Their inclusion in the educational process produced beneficial effects on physical development, contributing both to increases in height and to the maintenance of a balanced body mass index (BMI). At the same time, notable improvements were observed in fundamental motor skills such as speed, strength, and coordination, confirming their value as an active and efficient teaching method.

An important outcome of the research is the reduction of initial differences between boys and girls in terms of certain somatic characteristics and motor performance, suggesting that dynamic games provide an inclusive and equitable environment for development. The findings are consistent with current trends in the specialized literature, which emphasize the multifaced role of such activities – not only in motor development but also in fostering children's social, emotional, and educational growth.

Overall, dynamic games, emerge as a valuable pedagogical tool that is accessible, and highly effective. They successfully address both curriculum requirements and children's genuine needs for movement, interaction and self-expression.

These results strongly support the main research hypothesis, confirming that dynamic games represent a modern and effective teaching strategy for promoting balanced and motivating physical development in young school-age children.

**AUTHOR CONTRIBUTIONS**

Radu Adrian Rozsnyai, Paul Ovidiu Radu, Dumitru Rareș Ciocoi-Pop, Maria Daniela Macra-Oșorhean and Vasile Septimiu Ormenișan 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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# Trends in Agility Development Research Among Tennis Athletes between 2024 and 2025

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**ABSTRACT.** Agility and change-of-direction (COD) ability represent key determinants of tennis performance, yet the rapid evolution of research in this area over recent years has not been systematically characterized. The present descriptive meta-analysis examined scientific publications from 2024 and 2025 that investigated agility, reactive agility, or COD performance in tennis athletes. Sixteen peer-reviewed studies met inclusion criteria, encompassing intervention trials, test validation studies, observational designs, and systematic reviews. Quantitative analysis revealed an equal distribution of studies between 2024 and 2025, with a marked shift in research orientation: 2024 investigations predominantly emphasized test reliability and short-term interventions, whereas 2025 demonstrated greater methodological rigor through randomized controlled trials and evidence syntheses. Across empirical studies (n = 14), total participants numbered 929, with sample sizes ranging from 14 to 558 (M = 66.36, SD = 142.05, Md = 29.0). Youth and adolescent athletes constituted the majority of participants (62.5%), with comparatively fewer adult or elite samples. These findings suggest that agility research in tennis is transitioning from early validation phases toward applied, high-evidence investigations emphasizing neuromuscular, perceptual-cognitive, and ecological components of performance. The predominance of small, youth-focused studies underscores the need for multi-center trials, longitudinal designs, and elite-level analyses to ensure external validity. Collectively, the observed publication trends indicate a maturing research domain that increasingly integrates measurement precision with applied training science, reinforcing agility as a multifactorial determinant of modern tennis performance.

***Keywords:*** *agility training, change-of-direction, reactive agility, tennis performance, youth tennis athletes.*

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## INTRODUCTION

Agility has long been recognized as a critical determinant of success in many court and field sports, including tennis (Sheppard & Young, 2006). In the sport of tennis, players must repeatedly perform rapid accelerations, decelerations, and changes of direction in response to a moving ball, an opponent's position, and their own game plan (Cooke, Quinn, & Sibte, 2011). Historically, the physical prerequisite of being able to change direction efficiently—commonly termed change-of-direction speed (CODS)—has been studied extensively. However, more recently the conceptualization of agility has broadened to include reactive components, whereby athletes must not only change direction but do so in response to an external stimulus (Jones & Nimphius, 2019). This evolution in definition has substantial implications for training, testing, and research design.

In their seminal review, Sheppard and Young (2006) proposed that agility be defined as "a rapid whole-body movement with change of velocity or direction in response to a stimulus." They argued that agility comprises both trainable physical qualities such as strength and power, as well as perceptual–cognitive components including visual scanning, anticipation, and decision-making. Accordingly, they recommended that agility tests and training interventions address both physical and cognitive dimensions. This dual-component framework has since influenced much of the work in tennis and related racket sports.

In tennis specifically, the need to integrate perceptual–cognitive elements into agility training is heightened by the sport's dynamic and unpredictable nature. According to Cooke et al. (2011), classical testing protocols in tennis frequently captured only planned directional changes, offering limited insight into agility as executed in match play. Their work underscored the requirement for tennis-specific agility testing that incorporates reactive stimuli, decision-making under time constraints, and sport-specific movement demands.

Over the past decade, investigations in tennis agility training have expanded beyond purely physical drills toward integrated programmes that target neuromuscular control, reactive responsiveness, and on-court specificity. For example, plyometric training has been shown to improve acceleration, CODS, and reactive agility in young tennis players (Sinkovic, Novak, & Foretić, 2023). These findings align with broader meta-analytical work in youth sports demonstrating moderate effects of neuromuscular training on agility outcomes (Volk et al., 2023).

Despite these advances, reviews in racket sports have noted several research gaps: (a) a preponderance of small-scale pilot studies with limited sample sizes, (b) a focus on youth populations rather than adult or elite cohorts, and (c) a lack of longitudinal follow-through to determine transfer into match performance (Fernández-Fernández, de Villarreal, & Sanz-Rivas, 2016). In tennis, performance demands are evolving as the game becomes faster and more multidirectional; players must cover more ground earlier, reach balls at greater distances, and recover more quickly (Kovacs, 2007). Thus, the impetus for research into agility training is perhaps stronger than ever.

In this context, understanding the temporal trend of research publication — particularly in the recent years of 2024 and 2025—offers insight into how the field is developing. An analysis of what kinds of studies are being published (validation, intervention, systematic review), who the samples are (youth, collegiate, elite), and the scale of those studies (sample sizes) can reveal whether the domain is transitioning from foundational measurement work to applied, high-evidence intervention trials. Such a shift would be expected as the field matures: measurement reliability must be established before large-scale interventions can be reliably implemented and evaluated. Moreover, tracking the age groups of athletes studied informs whether research is aligning with key developmental stages or whether gaps remain (for example, in adult competitive populations).

The present work aims to map and interpret the recent surge of research on agility and change-of-direction in field tennis athletes. By conducting a descriptive statistical analysis of published studies in the 2024–2025 period, the current investigation will identify prevailing study types, sample demographics, and sample sizes. This mapping will inform future research directions, highlight emerging methodological trends, and suggest practical implications for training and testing practice in tennis performance preparation.

## MATERIAL AND METHODS

A descriptive meta-analysis was conducted to examine recent trends in agility-related research among field tennis athletes published during the years 2024 and 2025. The primary objective was to evaluate the evolution of research interests, methodological characteristics, and participant demographics, as well as to identify potential future research directions. The design of the present study was observational and descriptive in nature, focusing on the quantitative and qualitative synthesis of published scientific articles.

Scientific articles published between January 2024 and October 2025 were identified in high-impact, peer-reviewed journals with an established reputation in the sport and exercise sciences field, including PeerJ, Frontiers in Psychology, Frontiers in Sports and Active Living, Applied Sciences, International Journal of Sports Physiology and Performance, International Journal of Sports Medicine, BMC Sports Science, Medicine and Rehabilitation, and Journal of Human Kinetics. Only studies explicitly addressing agility, change-of-direction speed, or reactive agility in field tennis athletes were considered.

Articles were included if they (a) presented an empirical investigation or systematic review focused on agility training or assessment in tennis, (b) reported participant sample sizes, and (c) were published within the 2024–2025 period. Studies that analyzed sports other than tennis were excluded, as were editorials, conference abstracts, and non-peer-reviewed publications.

For each included study, the following variables were extracted: publication year, journal, study design, sample size, participant age group, and primary methodological approach (e.g., intervention, test validation, systematic review). Studies were categorized as either empirical (intervention, validation, or observational) or synthetic (systematic review or meta-analysis).

Descriptive statistical analyses were performed to summarize publication characteristics. Frequencies and percentages were calculated for categorical variables (publication year, study type, and age group). For empirical studies, sample-size distributions were analyzed using measures of central tendency and dispersion, including mean, median, standard deviation, range (minimum–maximum), and skewness. Statistical calculations were performed using IBM SPSS Statistics version 29.0. The level of analysis was descriptive, without inferential testing, as the primary objective was to map research trends rather than assess treatment effects.

## RESULTS

A total of 16 peer-reviewed studies met the inclusion criteria, published evenly across the two target years (n = 8 in 2024; n = 8 in 2025). Of these, 14 were empirical investigations and 2 were systematic reviews or meta-analyses. The majority of studies (56.3%) were classified as intervention-based designs, while 18.8% focused on test validation and reliability, 12.5% were observational or longitudinal, and 12.5% were systematic reviews or meta-analyses.

Across empirical investigations, the total number of participants analyzed was 929. Sample sizes ranged from 14 to 558 participants (M = 66.36, SD = 142.05, Md = 29.0). The wide range reflects the inclusion of one large observational dataset, which produced a positively skewed distribution (skewness = 3.01). Excluding this outlier, the adjusted mean sample size was 33.2 (SD = 13.6), indicating that most empirical studies were small-scale, with fewer than 35 participants.

Youth and adolescent populations represented the majority of research samples (62.5%), typically ranging from 10 to 16 years of age. Studies involving adult or elite players accounted for 25%, while only 12.5% examined collegiate or semi-professional athletes aged 20 years or older.

**Table 1.** Data collected for the meta-study

| # | Short Citation | Year | Journal | Study Type | Sample Size | Age Group |
|---|---|---|---|---|---|---|
| 1 | Zhou et al. (2024). PeerJ, 12, e18263. https://doi.org/10.7717/peerj.18263 | 2024 | PeerJ | Intervention (3-week MDST) | 19 | 20-24 |
| 2 | Kaya et al. (2024). Appl Sci, 14(20), 9266. https://doi.org/10.3390/app14209266 | 2024 | Applied Sciences (MDPI) | Test reliability / validation | 58 | 10y |
| 3 | Guo et al. (2024). Front Physiol, 15, 1449149. https://doi.org/10.3389/fphys.2024.1449149 | 2024 | Frontiers in Physiology | Systematic review | 18 studies | - |
| 4 | D'Hondt & Chapelle (2024). Int J Sports Med, 45(6), 436–442. https://doi.org/10.1055/a-2231-9630 | 2024 | Int J Sports Med | Longitudinal observational | 558 (323 M, 235 F) | 6–13 y |
| 5 | Horička et al. (2024). Appl Sci, 14(15), 6391. https://doi.org/10.3390/app14156391 | 2024 | Applied Sciences (MDPI) | Test validation (DRAT) | 14 (elite male volley-ball players; method relevant to tennis) | Adults / elite |
| 6 | Selmi et al. (2024). Appl Sci, 14(3), 1070. https://doi.org/10.3390/app14031070 | 2024 | Applied Sciences (MDPI) | Intervention (6-week) | 28 | 11–14 y |
| 7 | Trecroci et al. (2024). Int J Perf Anal Sport, 25(4), 675–686. https://doi.org/10.1080/24748668.2024.2437598 | 2024 | Int J Performance Analysis in Sport | Observational / validation | 31 | U12, U14 and U17 (age brackets) |
| 8 | Widodo et al. (2024). Pedagogy Phys Cult Sport, 28(4), 249–255. https://doi.org/10.15561/26649837.2024.0401 | 2024 | Various (peer-reviewed outlets) | Interventions (circuit / SAQ / combined) | 14 | 15-17 |
| 9 | Fernández-Fernández et al. (2025). Int J Sports Physiol Perf, 20(9), 1184–1190. https://doi.org/10.1123/ijspp.2024-0426 | 2025 | IJSPP (Human Kinetics) | Intervention (RCT / controlled) | 31 | 16 |

| # | Short Citation | Year | Journal | Study Type | Sample Size | Age Group |
|---|---|---|---|---|---|---|
| 10 | Zhou Y et al. (2025). BMC Sports Sci Med Rehabil, 17, 172. https://doi.org/10.1186/s13102-025-01219-x | 2025 | BMC Sports Sci Med Rehabil | Systematic review & meta-analysis | 23 studies | - |
| 11 | Munivrana et al. (2025). Front Sports Act Living, 7, 1486777. https://doi.org/10.3389/fspor.2025.1486777 | 2025 | Frontiers in Sports & Active Living | Validation / discriminative validity | 33 | 10–12 y |
| 12 | Oliveira et al. (2025). Front Sports Act Living, 7, 1571019. https://doi.org/10.3389/fspor.2025.1571019 | 2025 | Frontiers in Sports & Active Living | Intervention (6-week) | 20 | 10–14 y |
| 13 | Wang & Xu (2025). Front Psychol, 16, 1539739. https://doi.org/10.3389/fpsyg.2025.1539739 | 2025 | Frontiers in Psycholog | Intervention (single-session) | 47 | 15-16 |
| 14 | Zhou Z et al. (2025). PeerJ, 13, e19339. https://doi.org/10.7717/peerj.19339 | 2025 | PeerJ | Intervention | 22 | 21-23 |
| 15 | Morais et al. (2024). J Hum Kinet, 95, 173–185. https://doi.org/10.5114/jhk/189691 | 2025 | PeerJ / Frontiers / Human Kinetics | RCTs / controlled trials | 24 | 13 |
| 16 | Ćorilić et al. (2025). Exerc Qual Life, 17(1), 37–44. https://doi.org/10.31382/eqol.250604 | 2025 | Various indexed journals | Intervention / comparison | 30 | 20-35 |

A clear temporal trend was observed. Studies published in 2024 were dominated by test validation and short-term intervention designs, whereas 2025 demonstrated a marked shift toward controlled interventions and synthesis studies (systematic reviews and meta-analyses). This transition indicates a progressive maturation of the research domain from methodological validation to applied evaluation.

The most frequent publication sources were *Frontiers in Sports and Active Living*, *Applied Sciences (MDPI)*, and *PeerJ*. Collectively, these accounted for 68.7% of all studies. The prevalence of publications in established international journals underscores a growing global interest in agility development within tennis performance research.

## DISCUSSION

The present descriptive meta-analysis reveals an emerging consolidation of agility-related research within tennis over the past two years. The equal distribution of studies between 2024 and 2025, coupled with the shift from validation-oriented designs to controlled interventions and meta-analytical syntheses, reflects a field in transition toward methodological refinement and evidence integration.

The predominance of youth and adolescent samples suggests that agility continues to be viewed as a foundational performance determinant in long-term athlete development models. These findings are consistent with previous reviews emphasizing early-stage neuromuscular and perceptual-cognitive conditioning as critical to agility skill acquisition (Chaabene et al., 2019; Sheppard & Young, 2006). However, the relative scarcity of elite or adult player studies indicates a research gap in the later stages of athlete performance optimization. Elite-level tennis requires rapid perception-action coupling and anticipatory skill (Kovacs, 2009), yet the evidence base for targeted agility interventions in this population remains limited.

The observed methodological shift toward randomized and controlled trials in 2025 aligns with broader trends in applied sport science, wherein researchers increasingly prioritize reproducibility and ecological validity (Nakamura et al., 2020). Controlled intervention designs, particularly those integrating perceptual-cognitive agility tasks, provide stronger evidence for causality and transfer to match performance. Nevertheless, the median sample size of only 29 participants indicates a persistent challenge of limited statistical power, echoing methodological concerns raised in recent systematic reviews on sport-specific agility training (Young et al., 2015).

The growing appearance of systematic reviews and meta-analyses in 2025 further supports the notion that the research base on tennis agility is reaching critical mass. Such syntheses not only aggregate existing evidence but also provide standardized frameworks for evaluating methodological quality and intervention efficacy. The current findings therefore suggest that agility research in tennis has entered a consolidation phase, characterized by both critical synthesis and a movement toward ecological and performance-based assessments.

From a developmental standpoint, the emphasis on youth samples may reflect accessibility and the pedagogical focus of tennis academies, yet it limits generalizability to higher performance tiers. Future investigations should explore inter-age transfer effects, examining whether agility training benefits established in early adolescence persist or evolve across maturation stages. Additionally, integrating biomechanical, perceptual-cognitive, and match-play analyses would advance understanding of agility as a multidimensional construct that encompasses motor coordination, anticipation, and decision-making under pressure.

## CONCLUSIONS

The analysis of recent agility-related research in tennis demonstrates a balanced publication frequency between 2024 and 2025 but a meaningful evolution in research orientation. Whereas 2024 studies predominantly emphasized test development, reliability, and short-term interventions, the 2025 corpus reflected a methodological advancement toward controlled trials and evidence synthesis. Empirical studies remain largely small in scale, with modest participant numbers and an overrepresentation of youth athletes.

These trends collectively indicate a research domain progressing toward scientific maturity. Continued advancement will depend on expanding sample sizes, enhancing methodological rigor, and increasing representation of elite and professional players. Future studies should aim to combine physical, biomechanical, and perceptual-cognitive measures of agility, adopt multi-center experimental designs, and evaluate long-term transfer effects to actual match performance.

Overall, the descriptive trends from 2024 to 2025 highlight growing scholarly attention to agility in tennis as both a determinant of performance and a trainable capacity. This sustained interest suggests that agility research in tennis is transitioning from experimental innovation to applied integration, positioning the field for more comprehensive and ecologically valid investigations in the coming years.

## AUTHOR CONTRIBUTIONS

All three authors contributed equally to the conception and design of the study, data collection, analysis, and interpretation of the results. Furthermore, all authors were actively involved in drafting the manuscript and critically revising it for important intellectual content. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

## CONFLICT OF INTEREST

The authors declare no conflict of interest related to the present study. 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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# Mathematical Equations Associated with Spline Interpolation for Determining and Analyzing Tennis Shots Trajectory and Velocity

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**ABSTRACT. Aim:** This study investigated the application of spline interpolation for analyzing tennis ball trajectories and velocities. The motivation stemmed from the growing role of technology in sports performance and the need for quantitative tools that enable precise technical evaluation. The objective was to demonstrate that mathematical equations derived from spline interpolation can accurately describe shots trajectories and velocities, providing useful feedback for coaches and athletes. **Material and Methods:** A 15-year-old male tennis player executed 10 shots, including forehand (flat and topspin), backhand (flat and topspin), and serves. Distances and ball heights were measured manually at fixed points (0, 5, 10 m, landing), with times recorded via stopwatch. Curve Expert Professional was used to generate polynomial and trigonometric functions for trajectory modeling. **Results:** The analysis identified differences in maximum height and velocity between shot types. Topspin shots showed higher arcs and lower velocities, while flat shots produced flatter trajectories and higher speeds. Serves revealed distinct parameters influenced by toss height and angle. Equations reflected these dynamics and allowed interpolation of intermediate points (see Table 1, Figure 1). **Discussion:** The findings confirmed the suitability of spline interpolation, consistent with prior research (Cross, 1999b; Elliot et al., 2003). Despite limitations related to manual measurement and a single participant, the method proved reliable. Broader applications could integrate motion capture

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and sensors. **Conclusions:** Spline interpolation represents a feasible and effective approach for shot analysis in tennis, offering coaches a practical, science-based tool for technical optimization.

***Keywords:*** *tennis; biomechanics; spline interpolation; trajectory; velocity*

## INTRODUCTION

Modern sports, and in this case tennis, require athletes to master not only physical and tactical skills but also to adapt to new scientific and technological tools (Berry, 2020; Borisova, 2012), offer attention to health issues that can come along with sports practice and the means of therapy that can prevent and heal these issues as shown by Balla and Hanțiu (2019), and Pop and Chihaia (2015). Performance analysis has shifted towards quantitative methods, and mathematical modeling plays a central role in biomechanics as other studies (Gomboș, Gherman, Pătrașcu & Radu, 2017) have shown. Previous studies emphasized how variables such as direction, length, speed, spin, and trajectory influence shots efficiency (Șerban, 2020). However, fewer approaches have directly applied interpolation methods to describe ball movement. The present study addresses this gap by applying spline interpolation to tennis shots, aiming to evaluate its capacity to model ball flight with accuracy and provide applied insights for coaching. Additionally, the study determines the maximum height of the ball along its trajectory and calculates the velocity at that specific point, offering a more detailed understanding of the ball's motion dynamics.

## MATERIAL AND METHODS

### Participant

A male athlete aged 15 years, height 173 cm, weight 59 kg, actively engaged in competitive tennis. The subject executed 10 shots: two flat forehands, two topspin forehands, two flat backhands, two topspin backhands, and two serves.

### Procedure

#### *1) Maximum height on the trajectory*

Each shot was monitored for ball position at specific distances. Measurements were taken at contact ($D_0$=0 m), $D_1$=5 m, $D_2$=10 m, and at landing ($D_F$) when height ($H_F$=0 m). Heights (H) were recorded using manual rods graded in decimeters, while times (T) were measured using a stopwatch with two-decimal precision (Table 1).

**Table 1.** Measurements of shots.

| **No.** | **Type of shot** | **$D_0$=0 m, when:** | | **$D_1$=5 m, when:** | | **$D_2$=10 m, when:** | | **$H_F$=0 m (ball touches ground), when:** | |
|---|---|---|---|---|---|---|---|---|---|
| | | **$T_0$** | **$H_0$** | **$T_1$** | **$H_1$** | **$T_2$** | **$H_2$** | **$T_F$** | **$D_F$** |
| 1. | Forehand flat 1 | 0.00 | 1.1 | 0.22 | 1.2 | 0.44 | 0.9 | 0.89 | 17.2 |
| 2. | Forehand flat 2 | 0.00 | 1.1 | 0.20 | 1.1 | 0.42 | 0.9 | 0.91 | 18.9 |
| 3. | Forehand topspin 1 | 0.00 | 0.9 | 0.28 | 1.8 | 0.55 | 2.0 | 1.09 | 20.5 |
| 4. | Forehand topspin 2 | 0.00 | 0.8 | 0.29 | 2.0 | 0.56 | 2.4 | 1.04 | 22.9 |
| 5. | Backhand flat 1 | 0.00 | 1.1 | 0.23 | 1.3 | 0.41 | 1.1 | 0.80 | 16.0 |
| 6. | Backhand flat 2 | 0.00 | 1.0 | 0.25 | 1.1 | 0.43 | 0.9 | 0.92 | 17.3 |
| 7. | Backhand topspin 1 | 0.00 | 0.8 | 0.29 | 1.9 | 0.54 | 2.2 | 1.15 | 23.4 |
| 8. | Backhand topspin 2 | 0.00 | 0.8 | 0.27 | 2.2 | 0.52 | 2.4 | 0.99 | 22.3 |
| 9. | Service 1 | 0.00 | 2.3 | 0.18 | 2.0 | 0.32 | 1.4 | 0.50 | 14.8 |
| 10. | Service 2 | 0.00 | 2.4 | 0.15 | 1.9 | 0.30 | 1.3 | 0.45 | 12.9 |

Data Analysis: The analysis starts from the general functional relationship:

$$y=f(x), \text{ where:}$$

x=represents the distance traveled by the ball along its trajectory
y=represents the height of the ball relative to the ground.

This coordinate setup is used because, in a two-dimensional plane, the horizontal axis (Ox) naturally describes the forward displacement of the ball, while the vertical axis (Oy) expresses its height.

Data were then introduced into Curve Expert Professional 2.7.3 to fit equations representing the ball's trajectory. Polynomial and trigonometric functions were selected based on their ability to accurately mirror the physical reality of the motion. For topspin shots, spline interpolation offered smooth trajectories with realistic arcs.

### *2) Velocity*

Velocity was decomposed into horizontal and vertical components and combined using the Pythagorean theorem to obtain total velocity (Cross, 2003). The vertical velocity reflects the variation in the ball's height along the OY axis and is determined by differentiating the spline interpolation function y=f(x). Its value is obtained through the relation:

$$v_v = f'(x) \times v_o, \text{ where:}$$

$v_v$=vertical velocity,
f′(x)= is the derivative of the trajectory at that point and vov_ovo the horizontal velocity,
$v_o$=horizontal velocity.

Determining both vertical and horizontal velocity components is essential, as the ball's motion occurs in three-dimensional space, involving simultaneous changes in direction, height, and distance. The total velocity is therefore obtained as the vectorial resultant of these components:

$$v = \sqrt{v_o^2 + v_v^2}$$

This approach ensures a realistic representation of the ball's flight, enabling precise analysis of the maximum height and speed at that point.

## RESULTS

### 1) Maximum height on trajectory

The table (Table 2) summarizes the results obtained from applying the mathematical models to the ten analyzed tennis shots. The main objective of this analysis was to identify the maximum height point ($H_{max}$) reached by the ball in each trajectory, as well as to determine the distance from the starting point at which this value occurs.

**Table 2.** Equations generated by Curve Expert.

| Nr crt. | Type of shot | $H_{max}$ (m) | Distance (m) | Equation | f(x) | f '(x) |
|---|---|---|---|---|---|---|
| 1 | Forehand flat 1 | 1.21 | 4.26 | $y = a + b \times \cos(c \times x + d)$ | 1.21 | -0.008 |
| 2 | Forehand flat 2 | 1.21 | 3.21 | $y = a + b \times \cos(c \times x + d)$ | 1.12 | -0.004 |
| 3 | Forehand topspin 1 | 2.01 | 8.65 | $y = a \times x^2 + b \times x + c$ | 2.01 | 0.003 |
| 4 | Forehand topspin 2 | 2.42 | 10.12 | $y = a \times x^2 + b \times x + c$ | 2.41 | 0.005 |
| 5 | Backhand flat 1 | 1.34 | 4.32 | $y = a + b \times \cos(c \times x + d)$ | 1.34 | -0.01 |
| 6 | Backhand flat 2 | 1.15 | 4.41 | $y = a + b \times \cos(c \times x + d)$ | 1.16 | -0.006 |
| 7 | Backhand topspin 1 | 2.25 | 10.89 | $y = a \times x^2 + b \times x + c$ | 2.23 | 0.004 |
| 8 | Backhand topspin 2 | 2.51 | 11.45 | $y = a \times x^2 + b \times x + c$ | 2.53 | 0.007 |
| 9 | Service 1 | 2.3 | 0 | $y = \frac{a + b \times x}{1 + c \times x + d \times x^2}$ | 2.31 | -0.07 |
| 10 | Service 2 | 2.4 | 0 | $y = \frac{a + b \times x}{1 + c \times x + d \times x^2}$ | 2.4 | -0.1 |

In Curve Expert, the maximum height $H_{max}$ for each of the ten trajectories was determined by identifying the local extremum of the chosen interpolation function. The function value at this point, f(x), and its derivative, f′(x), were calculated to validate the model and to estimate the ball's velocity at the maximum height. The derivative reflects the vertical component of velocity, which, combined with the horizontal velocity, provides the total speed at that point. Differences between $H_{max}$ and f(x) were generally small (5–10 cm), indicating a good fit given the manual measurements and limited data points.

Flat shots reached maximum heights of about 1.2–1.3 m, with the peak occurring in the first third of the trajectory (25–35% of total distance), reflecting a fast, direct execution aimed at reducing the opponent's reaction time. In contrast, topspin shots reached heights over 2.4 m, with the maximum generally after half of the trajectory (50–55%), producing a slower, arched flight for greater depth and safety. Serves exhibited high $H_{max}$ values similar to topspin shots, but the peak occurred at impact (0% of the trajectory), consistent with the descending path of the ball immediately after the hit.

**2) Velocity**

The table below summarizes the dynamic analysis of eight tennis shots for which the ball's velocity at maximum height ($H_{max}$) could be determined. The main goal was to quantify the horizontal, vertical, and total velocity components at that point, based on measured data and the derivatives of the trajectory function.

For each shot, the distance and time corresponding to Hmax were first determined via interpolation. The horizontal velocity was calculated as the distance traveled over time, representing the ball's forward motion. The vertical velocity was derived from the trajectory function's slope, multiplied by the horizontal velocity to estimate the speed of ascent or descent at the peak.

The total velocity at $H_{max}$ was then obtained using $v = \sqrt{v_o^2 + v_v^2}$. Results (Table 3) are presented in meters per second and kilometers per hour for easier comparison in a sporting context.

Flat shots, whether forehand or backhand, recorded the highest total velocities among all groundstrokes, ranging from 72 to 90 km/h, reflecting an aggressive style aimed at accelerating play and finishing points quickly. Forehand flats reached up to 90 km/h, while backhand flats were slightly lower, between 72 and 78 km/h, indicating effective force transfer and intent to end rallies rapidly.

Topspin shots, both forehand and backhand, showed moderate total velocities between 64 and 72 km/h, typical of a more strategic style focused on placement, depth, and control. While slower than flat shots, they provide greater consistency and safety during rallies. Similar velocities for forehand and backhand suggest a uniform technique, though some backhand examples indicate less mastery, as speeds did not significantly exceed flat shot values (Mora, S., & Knottenbelt, W., 2017).

**Table 3.** Velocity results.

| No. | Type of shot | Distance to $H_{max}$ (m) | Time at $H_{max}$ (Sec) | Horizontal velocity (m/s) | Vertical velocity (m/s) | Total velocity (m/s) | Total velocity (km/h) |
|---|---|---|---|---|---|---|---|
| 1 | Forehand flat 1 | 4.26 | 0.18 | 22.78 | -0.18 | 22.78 | 82.99 |
| 2 | Forehand flat 2 | 3.21 | 0.12 | 25.08 | -0.10 | 25.08 | 90.29 |
| 3 | Forehand topspin 1 | 8.65 | 0.47 | 18.13 | 0.05 | 18.13 | 65.28 |
| 4 | Forehand topspin 2 | 10.12 | 0.56 | 17.94 | 0.09 | 17.94 | 64.42 |
| 5 | Backhand flat 1 | 4.32 | 0.19 | 21.71 | -0.22 | 21.71 | 78.16 |
| 6 | Backhand flat 2 | 4.41 | 0.22 | 19.95 | -0.12 | 19.96 | 71.78 |
| 7 | Backhand topspin 1 | 10.89 | 0.58 | 18.74 | 0.07 | 18.74 | 67.42 |
| 8 | Backhand topspin 2 | 11.45 | 0.57 | 19.91 | 0.14 | 19.91 | 71.64 |
| 9 | Service 1 | 5-10* | 0.18-0.32* | 35.71 | -4.29 | 35.97 | 129.5 |
| 10 | Service 2 | 5-10* | 0.15-0.30* | 33.33 | -4.00 | 33.52 | 120.7 |

*=were calculated for the trajectory segment between 5 and 10 meters from the moment of impact.

Serves produced the highest total speeds overall, approximately 120–130 km/h over the 5–10 meter trajectory segment. Although these speeds do not correspond to the maximum height point (Hmax), they represent the ball's real dynamics immediately after impact. Hmax for the serve occurs at the moment of contact, where time is zero, making standard calculations impossible. Nonetheless, the results confirm the serve's explosive nature and its decisive role in controlling match tempo. Considering a player height of 173 cm, Hmax should exceed 250 cm, according to Elliot, Reid, & Crespo (2003).

## DISCUSSION

The study demonstrated that spline interpolation is an effective modeling tool for tennis shots trajectories. Its capacity to deliver continuous curves and smooth transitions reduces errors found in high-degree polynomial fitting (Tamborrino, Falini, & Mazzia, 2024). These findings are consistent with existing biomechanical studies that examined tennis shots using advanced data analysis (Elliot, Reid, & Crespo, 2003; Sprigings et al., 1994). Flat shots confirmed their advantage in speed and penetration, while topspin shots highlighted control and higher clearance over the net, aligning with prior physics-based research (Cross, 1999a, 1999b).

Although the present study involved a single participant and manual measurements, the accuracy of the results validates the approach. Future work should employ motion capture systems, GPS, LIDAR, or high-speed cameras to expand precision. Broader samples would allow more robust conclusions applicable across player categories. Nevertheless, this study shows that coaches and athletes can already apply spline interpolation to monitor training progress and refining technique.

## CONCLUSIONS

Spline interpolation offers a scientifically grounded yet accessible approach for analyzing tennis shotss. It allows coaches to visualize trajectories, quantify velocity, and differentiate between shot types. The method bridges theoretical physics and applied sports practice, creating a modern tool for enhancing performance. Coaches can use it to provide feedback based on measured data, while athletes can understand how subtle technical changes influence ball behavior. Future research will strengthen its application, but even in its current form, spline interpolation enriches the analytical toolkit of tennis performance analysis.

## AUTHOR CONTRIBUTIONS

Andrei-Cătălin Brisc contributed with data collection, conceptualization, draft writing. Marius Alin Baciu and Alina Paula Apostu contributed with supervision, methodology design and manuscript review., Radu-Tiberiu Șerban contributed to the writing and formatting 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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