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PEDAGOGY of Physical Culture and Sports

ORIGINAL ARTICLE

Effects of an 8-week high-intensity interval training program on agility and intermittent endurance in junior badminton athletes

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

Abstract

Background and Study Aim: Sport-specific interval training is commonly incorporated into badminton conditioning programs to address the demands of repeated intensive actions performed during play. Training interventions focusing on the integration of sport-specific movement patterns under intermittent loading conditions are applied to influence performance-related outcomes during training and competition. Despite the use of different conditioning approaches, their relative effectiveness when integrated into regular training through sport-specific movement patterns remains a matter of practical interest. This study aimed to examine the effects of integrating an 8-week badminton-specific high-intensity interval training (BS-HIIT) program on agility and intermittent endurance in junior badminton athletes.

Material and Methods: Forty competitive junior badminton athletes (13–17 years) were allocated to either a BS-HIIT group (n = 20) or a control group performing conventional conditioning (n = 20). Both groups trained twice weekly for eight weeks, in addition to regular technical training. The BS-HIIT protocol consisted of court-based, multidirectional movements replicating badminton footwork at 85–95% HR_max, whereas the control group performed general aerobic and agility-based conditioning. Agility was assessed using the Badminton Shuttle Run Agility Test (BSRAT), and intermittent endurance was evaluated using the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). A two-way repeated-measures ANOVA, effect size calculations, correlation analysis, and responder analysis were conducted.

Results: Significant group × time interactions were observed for agility (η^2_p = 0.58) and intermittent endurance (η^2_p = 0.62). The BS-HIIT group demonstrated greater improvements in agility (−7.29%) and Yo-Yo IR1 performance (+31.4%) compared with the control group (−2.58% and +10.8%, respectively). A significant correlation between changes in intermittent endurance and agility was found only in the BS-HIIT group (r = −0.64, p = 0.002). A higher proportion of high responders was also observed following BS-HIIT.

Conclusions: An 8-week badminton-specific HIIT program is more effective than conventional conditioning in improving agility and intermittent endurance in junior badminton athletes. Integrating sport-specific movement patterns within high-intensity conditioning appears to promote transferable and consistent performance adaptations.

Keywords: badminton-specific training, high-intensity interval training, agility performance, intermittent endurance, junior athletes

Introduction

Competitive badminton requires players to repeatedly execute explosive movements and rapid changes of direction while sustaining technical precision and tactical decision-making throughout prolonged match play. Elite and junior badminton players are required to sustain high movement intensity while maintaining technical precision and tactical decision-making under fatigue conditions [1]. Match analysis studies have demonstrated that competitive badminton involves frequent accelerations, decelerations, lunges, jumps, and multidirectional footwork, with rally durations ranging from 5 to 10 s interspersed by brief recovery intervals [2, 3]. Consequently, agility and intermittent endurance are widely recognized as important physical determinants of badminton performance, particularly in athletes transitioning to higher competitive levels [4].

In recent years, the increasing physical demands

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of modern badminton, driven by faster rally tempos, increased rally density, and greater tactical variability, have intensified the need for effective and time-efficient conditioning strategies [5]. Junior athletes, in particular, must develop sufficient physiological capacity to tolerate repeated high-intensity actions while simultaneously refining sport-specific movement skills [6]. However, traditional conditioning approaches in youth badminton programs often rely on general aerobic running, non-specific interval training, or isolated agility drills. These approaches may not adequately reflect the biomechanical and metabolic demands of actual match play [7, 8]. This mismatch between training stimuli and competition demands may limit the transfer of conditioning adaptations to on-court performance.

High-intensity interval training (HIIT) has emerged as an effective conditioning method for improving aerobic capacity, anaerobic performance, and intermittent endurance across a wide range of team and individual sports [9, 10]. HIIT protocols are known to elicit central and peripheral adaptations, including improvements in stroke volume, oxygen delivery, mitochondrial function, and metabolic efficiency, even when total training volume is relatively low [11, 12]. In intermittent sports, HIIT has been shown to outperform moderate-intensity continuous training in enhancing repeated-sprint ability and high-intensity running performance [13].

Despite the well-documented physiological benefits of HIIT, recent literature has emphasized that the effectiveness of training interventions is strongly influenced by the principle of specificity [14, 15]. Similar sport-specific HIIT approaches have been successfully implemented in other intermittent sports, such as on-court HIIT in tennis and squash or movement-integrated HIIT in handball. These approaches demonstrated improved transfer to sport-specific performance compared with generic running-based protocols [13, 16, 17]. Training stimuli that closely replicate sport-specific movement patterns, decision-making constraints, and work–rest structures are more likely to produce transferable performance gains [15]. In this context, sport-specific HIIT, in which high-intensity intervals are embedded within technical and movement patterns relevant to the sport, has gained increasing attention. Such approaches aim to integrate physiological conditioning with neuromuscular and coordinative demands, thereby promoting more holistic performance adaptations.

Within badminton research, however, the evidence base for badminton-specific HIIT remains limited. While several studies have examined the physiological profiles of badminton players or compared general HIIT with continuous training, relatively few controlled interventions have investigated HIIT protocols explicitly designed around badminton footwork, multidirectional movement, and rally-like intensities, particularly in junior athletes [18, 19]. Moreover, existing studies often focus on isolated outcomes, such as aerobic capacity or sprint performance. They do not simultaneously examine agility and intermittent endurance, two interrelated performance components in badminton. It is also important to note that most HIIT interventions previously applied in racket sports have predominantly employed generic running-based formats or non-specific interval drills. These formats primarily target cardiovascular adaptations with limited representation of sport-specific movement mechanics [10, 12]. In contrast, badminton performance involves frequent multidirectional accelerations, lunges, split-step actions, and rapid recovery movements performed under high metabolic stress [2, 3, 7]. These biomechanical and neuromuscular demands are insufficiently replicated by linear or generalized HIIT protocols. This may limit the transfer of training adaptations to on-court performance [14, 15]. Consequently, the effectiveness of HIIT programs that explicitly integrate badminton-specific footwork patterns and rally-like work–rest structures remains insufficiently explored, particularly in youth and junior athlete populations.

Another gap in the literature concerns the mechanistic relationship between improvements in intermittent endurance and agility performance following sport-specific conditioning. Agility in badminton is a multidimensional construct influenced by speed, strength, neuromuscular coordination, eccentric control, and fatigue resistance [20]. From a theoretical standpoint, enhanced intermittent endurance may delay fatigue-related declines in neuromuscular function. This may support faster and more efficient change-of-direction movements during repeated high-intensity actions [21]. However, empirical evidence linking endurance adaptations to agility improvements within a badminton-specific training context remains scarce, particularly in youth populations. Given these considerations, there is a need for controlled experimental research that evaluates the effectiveness of a badminton-specific HIIT (BS-HIIT) protocol on key performance determinants while addressing issues related to specificity, transferability, and individual responsiveness. Investigating such interventions in junior athletes is important, as this developmental stage represents a period for establishing physiological and neuromuscular foundations that underpin long-term athletic progression.

Furthermore, previous HIIT studies in racket sports and badminton have largely reported group-mean performance responses, with limited consideration of inter-individual variability in

training adaptations [10, 18]. This represents a limitation, particularly in junior athletes, where differences in biological maturation, neuromuscular development, and training history may influence responsiveness to high-intensity training stimuli [15, 20]. Structured responder analysis has been increasingly advocated in applied sport science to enhance ecological validity and practical relevance. However, it remains rarely implemented in badminton-specific conditioning research [22, 23]. Addressing individual responsiveness may provide more nuanced insights into the consistency and effectiveness of sport-specific HIIT interventions in youth athlete development.

Several previous studies have investigated the effects of high-intensity interval training in racket sports and youth athlete populations, providing foundational evidence regarding the physiological benefits of HIIT [10, 12, 13, 18]. Systematic reviews and meta-analyses have demonstrated that HIIT is effective for improving aerobic capacity, repeated-sprint ability, and intermittent endurance across racket sports and combat-style activities [10, 12]. Similarly, intervention studies in youth athletes have reported positive adaptations following HIIT-based conditioning programs [13, 18]. However, these investigations have primarily employed generic running-based or non-specific interval formats and have focused predominantly on global physiological outcomes, with limited assessment of badminton-specific movement performance.

In badminton training practice, HIIT-based conditioning may be adapted to incorporate court-based, multidirectional footwork patterns representative of competitive match play. Such an approach allows high-intensity intervals to be embedded within movement structures that reflect the spatial and temporal demands of rallies. Performance assessment in this context commonly includes measures of agility and intermittent endurance, such as the Badminton Shuttle Run Agility Test (BSRAT) and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1), which reflect movement execution and repeated high-intensity effort capacity during rally-based play [3, 20, 24, 25, 26]. In junior athletes, these qualities are relevant in the context of ongoing neuromuscular and tactical development [22, 27]. Consideration of inter-individual variability in training responses represents an additional aspect of interest in youth conditioning research [28, 29].

Analysis of research findings has shown that high-intensity interval training is an effective conditioning approach for improving intermittent performance capacities in racket sports and youth athlete populations. Researchers emphasize the importance of aligning conditioning stimuli with the movement, temporal, and physiological demands of competitive play in order to support performance adaptations. At the same time, unresolved aspects related to the integration of sport-specific movement patterns, the interaction between key performance components, and individual variability in training responses continue to influence the practical application of HIIT in badminton training contexts. Addressing these considerations is essential for clarifying how conditioning strategies can be structured to support performance development in junior badminton athletes.

Based on the evidence discussed above, the evaluation of conditioning approaches that integrate sport-specific movement patterns within high-intensity interval training frameworks requires the identification of more effective training solutions. This study aimed to examine the effects of integrating an 8-week badminton-specific high-intensity interval training (BS-HIIT) program on agility and intermittent endurance in junior badminton athletes.

Materials and Methods

Participants

A total of 40 junior badminton athletes (male and female) aged 13–17 years participated in this study. Participants were recruited from established local badminton clubs in Surabaya City (Trisula Badminton Club and Training Ground Badminton Academy) through purposive sampling. This method is commonly applied in applied sport science research to ensure that participants possess relevant training backgrounds and performance characteristics [22, 27]. All athletes were actively engaged in systematic badminton training and competitive preparation at the regional level.

Eligibility criteria were defined to ensure sample homogeneity and to reduce confounding factors related to training status. Inclusion criteria consisted of the following:

- a minimum of four years of structured badminton training;
- a regular training frequency of at least four sessions per week;
- absence of musculoskeletal injury or illness for at least three months prior to the study.

Athletes with a history of cardiovascular, neurological, or metabolic disorders were excluded. Athletes participating in additional structured conditioning programs outside the study protocol were also excluded. These criteria are consistent with previous intervention studies investigating high-intensity training effects in youth and junior athletes [30].

Given the developmental characteristics of adolescent athletes, particular attention was paid to safety and training readiness. Prior to participation, all athletes underwent pre-participation screening. This screening included medical clearance from club-affiliated physicians and confirmation from

coaches regarding training history and current health status. Written informed consent was obtained from parents or legal guardians, and assent was obtained from the athletes, in accordance with ethical guidelines for research involving minors [31]. The study was approved in accordance with the seven ethical principles of the World Health Organization (WHO) under approval number 129206/UN38.III.3/TU.00.00/2025.

Following baseline testing, participants were matched according to ranked pretest agility and intermittent endurance scores, assessed using the Yo-Yo Intermittent Recovery Test Level 1, to ensure equivalence between groups. Participants were ordered based on baseline performance, and pairs with the most similar scores were formed. Within each matched pair, participants were alternately assigned to either the experimental group (badminton-specific HIIT; n = 20) or the control group (conventional training; n = 20). This matched-pair allocation procedure was conducted manually by the research team and was not randomized. Matching procedures are recommended in applied sport settings where full randomization may be constrained by logistical or ethical considerations, while still maintaining acceptable internal validity in training intervention studies [28, 32].

Throughout the intervention period, training attendance and compliance were closely monitored. Athletes who missed more than 10% of the total training sessions were excluded from the final analysis. This threshold is commonly used in exercise intervention studies to ensure sufficient training exposure and data integrity [13].

Research Design

This study employed a controlled experimental design with a pretest–posttest parallel-group approach. The study was conducted over an 8-week intervention period, following the Consolidated Standards of Reporting Trials (CONSORT) principles adapted for sports science research. A structured and controlled training schedule was applied to compare the effects of a badminton-specific high-intensity interval training (BS-HIIT) protocol with those of conventional conditioning training. The overall organization of the study included baseline testing, intervention implementation, training load monitoring, and post-intervention testing. An overview of the study design and experimental protocol is presented in Figure 1.

At baseline (week 0), all participants underwent pre-intervention assessments of agility and intermittent endurance. Following baseline testing, participants were matched based on initial

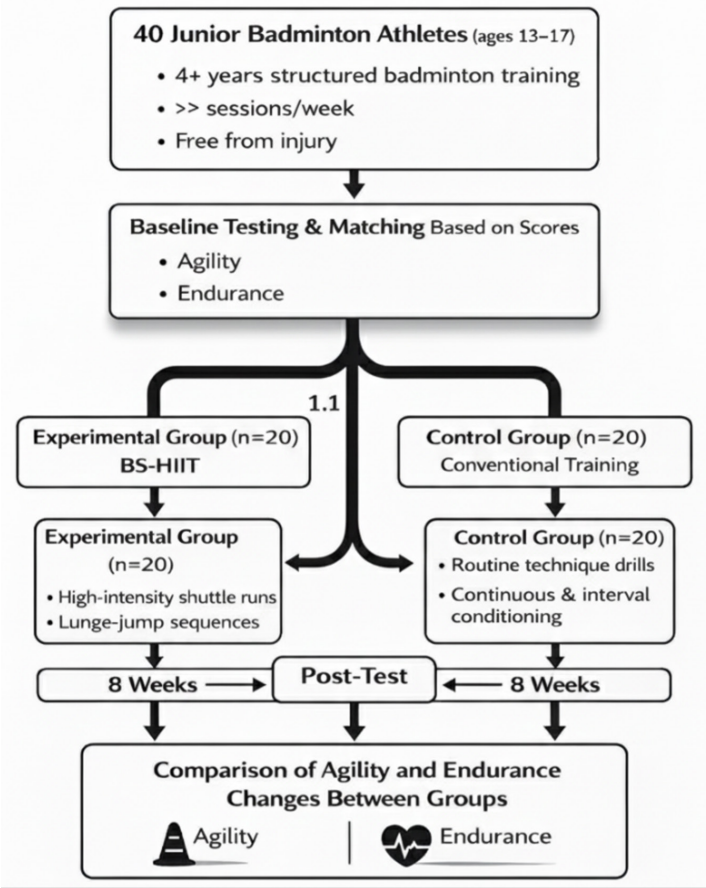

Figure 1. Study design and experimental protocol of the Badminton-Specific High-Intensity Interval Training (BS-HIIT) intervention.

performance scores and allocated into either the experimental group (BS-HIIT) or the control group (conventional training). Both groups continued their regular technical and tactical badminton training provided by their clubs. The conditioning component differed according to group assignment.

To control for training exposure, both groups completed two conditioning sessions per week, separated by at least 48 hours, in addition to routine badminton practice. Conditioning sessions were conducted on indoor badminton courts under the supervision of BWF-certified coaches and sport science researchers. Training attendance, session duration, and internal training load were monitored to ensure compliance and comparability between groups. A detailed description of the conditioning programs for both groups is provided in Table 1.

The conditioning training program constituted the primary intervention of this study. An overview of the conditioning characteristics for the experimental and control groups is presented in Table 1. The intervention was performed twice per week for eight weeks, while regular technical and tactical badminton training was maintained and not manipulated.

The intervention was periodized progressively across the 8-week program. Training intensity and complexity were increased every two weeks through manipulation of bout duration, movement complexity, and recovery time, following established principles of overload and progression in high-intensity training [27, 30]. A detailed description of the conditioning protocols applied across the intervention period is provided in Table 2.

Reactive change-of-direction (COD) tasks involved rapid changes in movement direction performed in response to randomized visual cues provided by the coach, indicating movement toward specific court zones. Game-like movement consisted of continuous multidirectional badminton footwork, including lunges, split steps, lateral shuffles, and recovery movements, performed across court areas without shuttle involvement. Smash–recovery multidirectional drills comprised simulated smash footwork followed by rapid recovery to the base position using forward, backward, and lateral movements. Intermittent rally simulation involved repeated high-intensity movement bouts structured to reproduce rally–rest patterns observed during badminton match play. The non-specific agility circuit included generic multidirectional drills without badminton-specific movement patterns, while the mixed aerobic–plyometric circuit combined cyclic aerobic exercises with basic plyometric tasks. Interval running was performed as repeated 2-min running bouts interspersed with 1-min passive recovery, whereas continuous running was conducted at a steady intensity of 65–75% HR_max for 15–25 min with progressive increases in duration.

Both groups completed two conditioning sessions per week over an 8-week intervention period (16 sessions in total). The experimental group followed a badminton-specific HIIT program, whereas the control group performed conventional conditioning with matched training frequency and session duration. Each conditioning session lasted approximately 25–30 min and consisted of a warm-up, a main conditioning phase, and a cool-down.

Measurement

Agility performance was assessed using a badminton-specific agility test designed to replicate multidirectional movement patterns commonly performed during competitive rallies [33]. The

Table 1. Conditioning training programs for experimental and control groups

Component	Experimental Group (BS-HIIT)	Control Group (Conventional Training)
Training frequency	2 sessions/week	2 sessions/week
Session duration	25–30 min	25–30 min
Warm-up (10 min)	Dynamic mobility, skipping, court footwork patterns	Jogging, dynamic stretching
Main training format	High-intensity interval training	Continuous and interval conditioning
Primary exercises	Multidirectional shuttle runs, lunge–jump sequences, lateral shuffles, smash-recovery footwork	Continuous running, agility ladder drills, basic plyometrics
Movement specificity	High (court-based)	Low–moderate (general conditioning)
Work–rest structure	30–40 s work / 20–30 s active recovery	Continuous or fixed intervals (1–3 min work)
Target intensity	85–95% HRmax, RPE 17–19	70–85% HRmax, RPE 13–16
Progression strategy	Increased repetitions, reduced recovery, added directional complexity every 2 weeks	Increased duration or repetitions
Cool-down (5 min)	Low-intensity movement, static stretching	Static stretching
Total intervention	8 weeks	8 weeks

Table 2. Detailed conditioning (intervention) programs for experimental and control groups (8 weeks, 16 sessions)

Week / Session (W–S)	Experimental Group – Badminton-Specific HIIT (BS-HIIT)	Control Group – Conventional Conditioning	Intensity Target
W1 – S1	Multidirectional shuttle (front–back–side), 3 × 30 s / 30 s	Continuous jogging + dynamic mobility, 15 min	85% HRmax, RPE 16
W1 – S2	Lateral shuffle + forward sprint, 3 × 30 s / 30 s	Agility ladder (basic patterns), 3 × 30 s	85% HRmax, RPE 16
W2 – S3	Lunge right–left + recovery step, 3 × 30 s / 30 s	Straight-line sprint drills, 6 × 20 m	85–88% HRmax
W2 – S4	Split-step → diagonal movement, 3 × 30 s / 30 s	Basic plyometric jumps (squat jumps), 3 × 10 reps	85–88% HRmax
W3 – S5	Court-based shuttle (6-point pattern), 4 × 30 s / 25 s	Interval running (1 min run / 1 min walk × 6)	88–90% HRmax
W3 – S6	Lunge + vertical jump, 3 × 35 s / 25 s	Agility cone drills (non-reactive), 4 × 30 s	88–90% HRmax
W4 – S7	Lateral shuffle + reactive COD, 4 × 30 s / 25 s	Continuous running, 18 min	88–90% HRmax
W4 – S8	Smash approach + recovery footwork, 3 × 35 s / 25 s	Basic plyometric circuit, 3 rounds	88–90% HRmax
W5 – S9	Random multidirectional shuttle, 4 × 35 s / 20 s	Interval running (90 s / 60 s × 6)	90–93% HRmax
W5 – S10	Lunge → jump → lateral recovery, 4 × 35 s / 20 s	Agility ladder (advanced patterns), 4 × 30 s	90–93% HRmax
W6 – S11	Continuous rally footwork simulation, 4 × 40 s / 20 s	Tempo running, 20 min	90–93% HRmax
W6 – S12	Diagonal sprint + backpedal, 4 × 35 s / 20 s	Cone shuttle run (linear), 4 × 40 s	90–93% HRmax
W7 – S13	Game-like random movement (cone/LED cue), 5 × 40 s / 20 s	Interval running (2 min / 1 min × 6)	93–95% HRmax
W7 – S14	Smash–recovery multidirectional, 4 × 40 s / 20 s	Agility circuit (non-specific), 4 rounds	93–95% HRmax
W8 – S15	Intermittent rally simulation, 5 × 40 s / 20 s	Continuous running, 22 min	93–95% HRmax
W8 – S16	COD under fatigue (lateral–forward patterns), 4 × 40 s / 20 s	Mixed aerobic–plyometric circuit	93–95% HRmax

test was conducted on an indoor badminton court with standardized markings corresponding to forward, lateral, diagonal, and backward movement directions. Participants started from the central base position and moved as quickly as possible to the designated targets following a fixed sequence. Performance was recorded as total completion time (s) using electronic timing gates (Brower Timing Systems, USA). Each participant completed two trials, separated by a 3-min passive recovery period, and the best performance was used for further analysis. This test has demonstrated good-to-excellent reliability (ICC = 0.87–0.94) and construct validity for assessing agility in racket sport athletes, including badminton players [16, 34]. A schematic representation of the test layout and movement sequence is shown in Figure 2.

The Badminton Shuttle Run Agility Test (BSRAT) is conducted on one half of a standard badminton court. The athlete stands approximately one meter behind the start/finish line while holding a badminton racket in the dominant hand. Upon the start signal or when the timing gate is triggered, the athlete sprints to the central square (point 1). From the center, the athlete moves to touch or knock over a shuttlecock placed at predetermined positions in eight different directions (points 2–8) following a fixed order. After each shuttlecock contact, the athlete returns to the central square and touches it with one foot before proceeding to the next direction. After completing the final shuttlecock contact, the athlete returns to the center and sprints back to the start/finish line to stop the timer. Each participant performs one familiarization trial followed by three to five valid trials, with sufficient passive recovery between attempts. Test performance is evaluated based on the total time required to complete the entire movement sequence, measured in seconds.

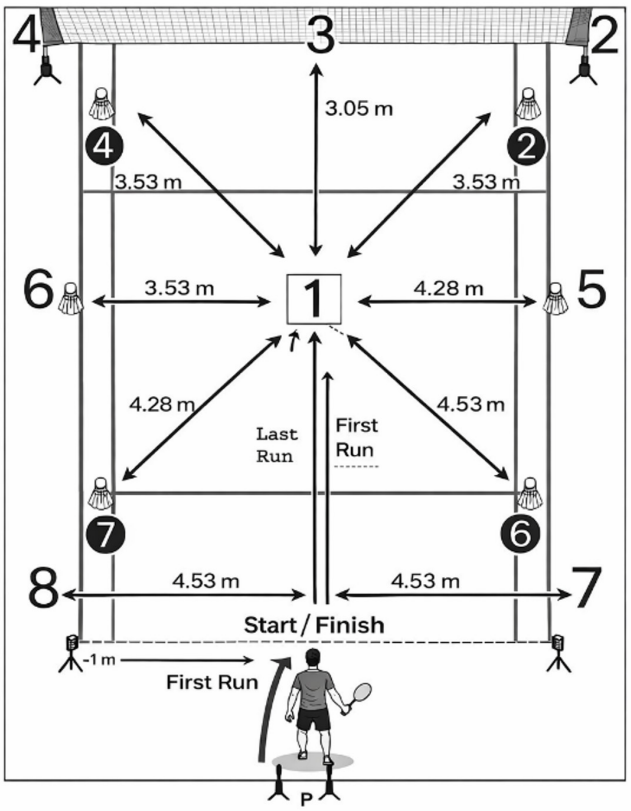

Figure 2. Badminton Shuttle Run Agility Test (BSRAT) [33]

The fastest valid trial is recorded as the final score. A time penalty of one second is added for each error, including failure to touch a shuttlecock or failure to touch the central square with the foot. Trials are repeated if the athlete performs the sequence in an incorrect order or does not complete the test. Shorter completion times indicate better agility and change-of-direction performance specific to badminton.

Intermittent endurance capacity was evaluated using the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) [24]. The test consists of repeated 20-m shuttle runs performed at progressively increasing speeds, interspersed with 10 s of active recovery, and continued until volitional exhaustion or failure to maintain the required pace on two consecutive occasions. Total distance covered (m) was recorded as the primary outcome variable. Heart rate was continuously monitored throughout the test using chest-strap heart rate monitors (Polar H10, Finland) to verify maximal effort. The Yo-Yo IR1 has demonstrated excellent test–retest reliability (ICC > 0.95) and is considered a valid measure of intermittent endurance in sports characterized by repeated high-intensity efforts, including badminton [25, 26].

Internal training load during each training session was quantified using the session rating of perceived exertion (sRPE) method [35]. Approximately 30 min after each session, athletes reported their perceived exertion using the Borg CR-10 scale [36]. Training load was calculated by multiplying session duration (min) by the reported RPE score and was expressed in arbitrary units (AU). The sRPE method has been shown to be a valid and reliable indicator of internal load in youth and adolescent athletes [37, 38].

Heart rate responses were recorded continuously during all training sessions using Polar H10 monitors [39]. Mean and peak heart rate values were extracted and expressed as a percentage of estimated maximal heart rate (%HR_max). Heart rate monitoring was used to verify training intensity and to ensure compliance with the prescribed high-intensity interval training protocol. This approach is widely recommended for physiological load monitoring in intermittent sports [17, 40].

All performance tests were conducted under standardized indoor conditions on a wooden badminton court, with ambient temperature maintained between 24–26°C. Prior familiarization sessions were conducted to minimize learning effects, and both the BSRAT and Yo-Yo IR1 have demonstrated acceptable test–retest reliability in adolescent and racket-sport populations (ICC > 0.85) [22, 24].

All measurements were conducted at baseline (pre-test) and after the intervention period (post-test) under standardized indoor conditions. Participants were instructed to refrain from vigorous physical activity for 48 h before testing and to maintain their usual dietary habits [41, 42] and hydration habits [43, 44]. All tests were administered by the same investigators using identical equipment and procedures to reduce measurement variability.

Agility performance was assessed using electronic timing gates (Brower Timing Systems, Draper, UT, USA) positioned at hip height (≈0.8 m) at the start/finish line. Athletes commenced each trial from a standardized standing start position with the lead foot placed 30 cm behind the gate to prevent premature triggering, and timing was initiated automatically upon breaking the infrared beam.

Heart rate (HR) responses during training sessions were continuously monitored using Polar H10 chest-strap monitors (Polar Electro Oy, Finland), which have demonstrated high validity for exercise HR measurement [45]. Maximal HR was estimated using an age-based equation (208 − 0.7 × age), and training intensity zones were defined relative to individual HR_max, with high-intensity efforts corresponding to 85–95% HR_max. Session compliance was verified through post-session HR data analysis. Both the BSRAT and Yo-Yo IR1 have demonstrated acceptable test–retest reliability in adolescent and racket-sport populations (ICC > 0.85) [24, 33].

Statistical Analysis

All data were analyzed using SPSS (version 27; IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as mean ± standard deviation (SD). Normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was verified using Levene's test. Baseline comparability between groups was examined using independent-samples t-tests.

To evaluate the effects of the intervention on agility (Badminton Shuttle Run Agility Test, BSRAT) and intermittent endurance (Yo-Yo Intermittent Recovery Test Level 1), a two-way repeated-measures analysis of variance (ANOVA) was performed with time (pre-test vs. post-test) as the within-subject factor and group (BS-HIIT vs. control) as the between-subject factor. Partial eta squared (η^2_p) was calculated to quantify the magnitude of the group × time interaction effects. Within-group changes were further quantified using Cohen's d, calculated from pre–post mean differences divided by the pooled standard deviation. Relative performance changes were expressed as percentage change ((post − pre) / pre × 100), and between-group effect sizes for change scores were calculated to support practical interpretation of training effects.

Associations between changes in intermittent endurance and agility performance were examined using Pearson's product–moment correlation coefficients within each group, with statistical significance determined using two-tailed testing. To examine inter-individual variability in training responses, a responder analysis was conducted by classifying athletes as high or low responders based on a median split of individual pre–post change scores within each group for both performance outcomes. The number and percentage of athletes in each category were calculated. Statistical significance was set at $p < 0.05$ for all analyses.

Results

A total of 40 junior badminton athletes completed the 8-week intervention and were included in the final analysis, with no dropouts due to injury or insufficient training compliance. Baseline characteristics were comparable between the badminton-specific HIIT (BS-HIIT) group and the control group, with no meaningful differences observed in age, sex distribution, anthropometric variables, training experience, or pre-intervention performance outcomes (Table 3).

Table 3. Baseline characteristics of the study participants (mean ± SD)

Variable	BS-HIIT (n = 20)	Control (n = 20)	p-value
Age (years)	15.15 ± 1.42	15.30 ± 1.34	0.73
Sex (male/female)	11 / 9	10 / 10	—
Height (cm)	161.20 ± 7.82	163.46 ± 7.78	0.36
Body mass (kg)	56.78 ± 8.68	57.00 ± 7.74	0.92
Training experience (years)	6.2 ± 1.24	6.0 ± 1.38	0.61
Agility (BSRAT, s)	17.16 ± 0.76	17.05 ± 0.91	0.66
Yo-Yo IR1 distance (m)	1139 ± 135	1123 ± 109	0.68

Note. Values are presented as mean ± SD. No significant between-group differences were observed at baseline ($p > 0.05$).

Table 3 shows that the BS-HIIT and control groups were comparable at baseline, with no significant differences in age, sex distribution, anthropometric variables, training experience, agility performance (BSRAT), or intermittent endurance (Yo-Yo IR1) ($p > 0.05$). Following confirmation of comparable baseline characteristics between groups (Table 3), the effects of the training intervention on agility and intermittent endurance performance were examined (Table 4).

Changes in agility and intermittent endurance performance over time are illustrated in Figure 3, while corresponding numerical values and effect size estimates are reported in Table 4. A two-way repeated-measures ANOVA revealed significant group × time interactions for both outcomes. The BS-HIIT group demonstrated a larger reduction in BSRAT completion time ($\Delta = -1.25$ s, $d = -1.61$) compared with the control group ($\Delta = -0.44$ s, $d = -0.47$), with a large proportion of explained variance ($\eta^2_p = 0.58$). Similarly, Yo-Yo IR1 performance increased substantially following BS-HIIT ($\Delta = +357$ m, $d = 2.48$), exceeding the improvement observed

Table 4. Effects of BS-HIIT on agility and intermittent endurance performance

Outcome	Group	Pre-test	Post-test	Δ Change	Cohen's d	η^2_p (Time × Group)
Agility (BSRAT, s)	BS-HIIT (n=20)	17.16 ± 0.76	15.91 ± 0.79	−1.25	−1.61	0.58
	Control (n=20)	17.05 ± 0.91	16.61 ± 0.93	−0.44	−0.47	
Yo-Yo IR1 (m)	BS-HIIT (n=20)	1138.6 ± 134.9	1495.7 ± 152.6	+357.1	2.48	0.62
	Control (n=20)	1122.8 ± 109.1	1244.5 ± 115.9	+121.7	1.08	

Note. Values are presented as mean ± SD. Δ Change represents the post–pre difference. Cohen's d reflects within-group standardized change. Partial eta squared (η^2_p) represents the magnitude of the group × time interaction derived from two-way repeated-measures ANOVA.

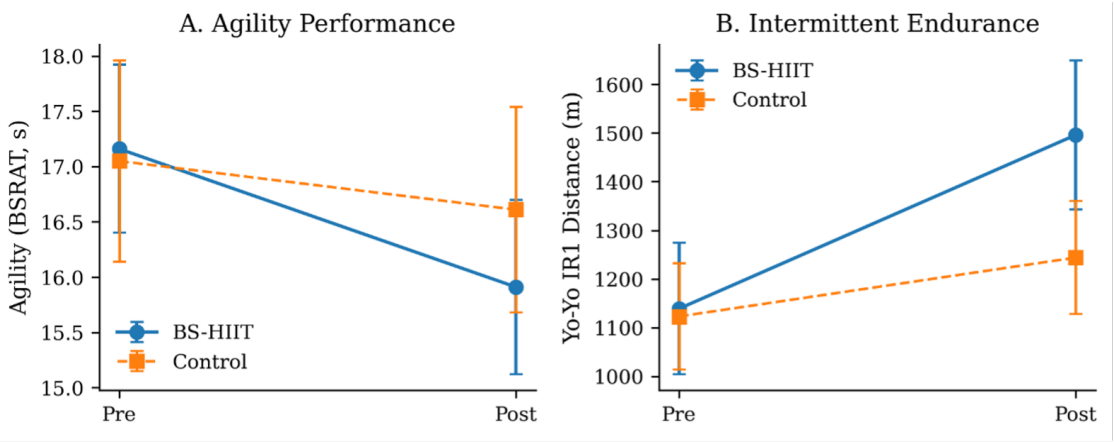

Figure 3. Change over time in performance outcomes

in the control group (Δ = +122 m, d = 1.08). The group × time interaction for intermittent endurance accounted for 62% of the explained variance (η^2_p = 0.62). To complement these findings, relative changes and between-group effect sizes were subsequently examined.

Relative percentage changes in performance outcomes and between-group effect sizes were examined to provide additional insight into the magnitude of training-induced adaptations following the intervention. An overview of relative (%) changes and between-group standardized differences for agility and intermittent endurance is presented in Table 5.

The results indicate that BS-HIIT elicited greater relative improvements in both agility and intermittent endurance compared with conventional training (Table 5). To further examine the relationship between adaptations in these performance outcomes, associations between changes in intermittent endurance and agility performance were analyzed (Table 6).

The relationships between individual changes in intermittent endurance and agility performance within each group are summarized in Table 6.

The relationship between changes in intermittent endurance and agility performance following the intervention is illustrated in Figure 4.

As shown in Figure 4, a significant negative correlation was observed in the BS-HIIT group (r = −0.64, p = 0.002), indicating that greater improvements in intermittent endurance were associated with larger reductions in agility completion time. No significant association was found in the control group.

Correlation analysis demonstrated a significant association between changes in intermittent endurance and agility performance within the BS-HIIT group, whereas no such relationship was observed in the control group. Given the observed inter-individual variability in training responses, athletes were subsequently classified according to their responsiveness to the intervention. The results of the responder analysis for agility and intermittent endurance improvements are presented in Table 7.

Responder analysis indicated a higher proportion of high responders in the BS-HIIT group compared with the control group for both agility and intermittent endurance outcomes (Table 7). Specifically, a greater percentage of athletes in the BS-HIIT group demonstrated meaningful improvements in BSRAT performance and Yo-Yo IR1 distance, whereas the control group showed a higher proportion of low responders across both performance measures.

Table 5. Relative (%) changes and between-group effect sizes following BS-HIIT

Outcome	Group	Pre-test	Post-test	% Change	Cohen's d (between-group)
Agility (BSRAT, s)	BS-HIIT	17.16 ± 0.76	15.91 ± 0.79	−7.29%	1.24
	Control	17.05 ± 0.91	16.61 ± 0.93	−2.58%	
Yo-Yo IR1 (m)	BS-HIIT	1138.6 ± 134.9	1495.7 ± 152.6	+31.4%	1.38
	Control	1122.8 ± 109.1	1244.5 ± 115.9	+10.8%	

Note. Percentage change was calculated as (post−pre)/pre × 100. Cohen's d represents the between-group standardized difference in change scores.

Table 6. Correlations between changes in intermittent endurance and agility performance

Variable Pair	r	p-value	Interpretation
Δ Yo-Yo IR1 vs. Δ BSRAT (BS-HIIT)	−0.64	0.002	Large
Δ Yo-Yo IR1 vs. Δ BSRAT (Control)	−0.31	0.18	Small–moderate

Note. Δ values represent post-test minus pre-test values. Negative correlation coefficients indicate that greater improvements in intermittent endurance were associated with larger reductions in agility completion time.

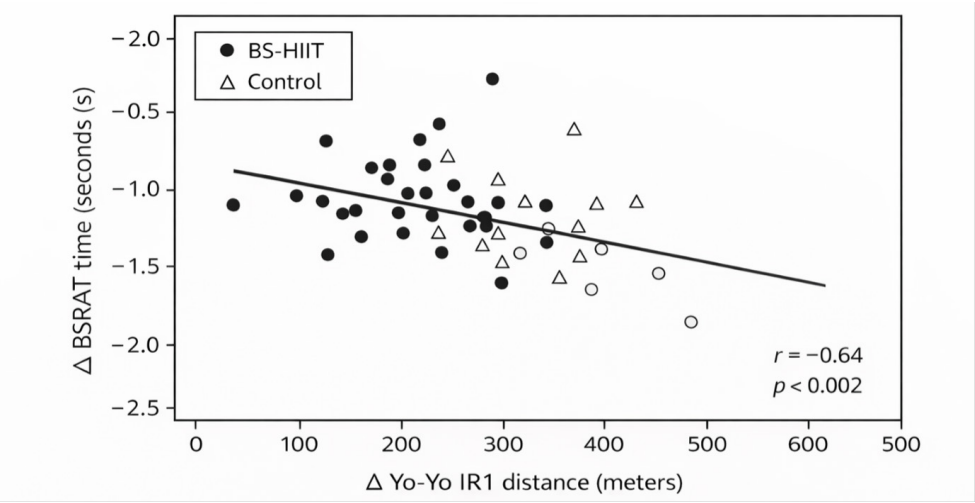

Figure 4. Relationship between changes in intermittent endurance (Δ Yo-Yo IR1) and agility performance (Δ BSRAT) following the intervention.

Table 7. Responder analysis for agility and intermittent endurance improvements

Outcome	Group	High Responders n (%)	Low Responders n (%)
Agility (BSRAT)	BS-HIIT	14 (70%)	6 (30%)
	Control	7 (35%)	13 (65%)
Yo-Yo IR1	BS-HIIT	15 (75%)	5 (25%)
	Control	8 (40%)	12 (60%)

Discussion

The present study investigated the short-term effects of a badminton-specific high-intensity interval training (BS-HIIT) program on physiological load, intermittent endurance, and agility performance in competitive badminton athletes. The main findings indicate that BS-HIIT induced greater improvements in Yo-Yo IR1 performance and agility (BSRAT) compared with conventional training, along with a higher internal load as reflected by heart rate distribution and energy expenditure. In addition, a significant association was identified between changes in intermittent endurance and agility performance, indicating interrelated adaptations between physiological capacity and sport-specific movement efficiency.

The BS-HIIT protocol elicited a higher internal load, as evidenced by greater time spent in high-intensity heart rate zones and increased total energy expenditure compared with the control condition. These findings suggest that BS-HIIT effectively replicated the intermittent, high-intensity physiological demands characteristic of competitive badminton rallies, which typically involve repeated accelerations, decelerations, and short recovery

periods [2, 3].

Sustained exposure to heart rates above 85–90% HR_max is known to stimulate central and peripheral cardiovascular adaptations, including increased stroke volume, improved oxygen delivery, and enhanced mitochondrial efficiency [46, 47]. The higher cumulative cardiovascular strain observed in the BS-HIIT group likely contributed to the greater gains in intermittent endurance capacity observed in the Yo-Yo IR1 test. These responses were achieved without extending total training duration, indicating the time efficiency of sport-specific HIIT as a conditioning strategy.

The improvement in Yo-Yo IR1 performance following BS-HIIT reflects an enhanced ability to tolerate repeated high-intensity efforts interspersed with brief recovery periods. In badminton, intermittent endurance is an important determinant of match performance, as players are required to sustain explosive movements and rapid changes of direction over prolonged match durations [8, 48]. These findings are consistent with previous research showing that high-intensity interval training produces greater improvements in intermittent endurance than moderate-intensity or non-specific conditioning programs [12, 13]. The badminton-specific design of the BS-HIIT drills likely enhanced training transfer by engaging sport-relevant muscle groups, movement patterns, and neuromuscular coordination under metabolic stress, supporting the principle of training specificity [15].

Agility performance, assessed using the BSRAT, improved to a greater extent in the BS-HIIT group than in the control group. This result suggests that repeated exposure to high-intensity, multidirectional movement tasks under fatigue enhanced the ability to execute rapid directional changes efficiently. Agility in badminton depends not only on speed but also on neuromuscular coordination, eccentric strength, and reactive control [49, 50].

The BS-HIIT protocol likely promoted neuromuscular adaptations by repeatedly challenging braking and re-acceleration capacities under time pressure and metabolic stress. These adaptations may include improved motor unit recruitment, enhanced intermuscular coordination, and greater movement economy during high-intensity actions [43, 44]. Such mechanisms help explain why agility gains were more pronounced in the BS-HIIT group despite similar technical training exposure between groups. A key finding was the significant correlation between changes in Yo-Yo IR1 performance and changes in BSRAT performance within the BS-HIIT group. Athletes who demonstrated greater improvements in intermittent endurance also exhibited larger enhancements in agility performance. This relationship was not observed in the control group, suggesting that the integration of endurance and movement-specific demands within the BS-HIIT protocol contributed to linking these adaptations.

This finding provides empirical support for a mechanistic linkage between physiological capacity and sport-specific performance. Improved intermittent endurance may delay fatigue-related neuromuscular impairments, allowing athletes to maintain rapid footwork, precise positioning, and efficient change-of-direction mechanics during repeated high-intensity efforts [23, 51]. Consequently, endurance adaptations should be viewed as foundational elements that support the execution of complex motor tasks in intermittent sports such as badminton.

From a theoretical perspective, the present results reinforce integrative models of performance adaptation that emphasize interactions between physiological, neuromuscular, and task-specific constraints. Rather than treating conditioning and skill development as separate entities, the BS-HIIT approach demonstrates that conditioning stimuli embedded within sport-specific contexts can simultaneously enhance physiological capacity and movement performance [52, 53]. The observed inter-individual variability in adaptation further supports contemporary frameworks advocating individualized training prescription and monitoring. Athletes may respond differently to identical training stimuli depending on baseline fitness, neuromuscular characteristics, and recovery capacity [29, 54]. Thus, integrating internal load monitoring with performance testing remains essential for optimizing training outcomes.

From an applied standpoint, the findings suggest that incorporating badminton-specific HIIT sessions into regular training programs can effectively improve both intermittent endurance and agility without increasing total training volume. Coaches may consider prioritizing drills that combine high-intensity movement, rapid directional changes, and short recovery intervals to maximize transfer to competitive performance. Monitoring heart rate responses and energy expenditure may assist practitioners in ensuring that training intensity remains within targeted physiological zones.

Beyond group-level effects, the responder analysis provides insight into the heterogeneity of training adaptations following the BS-HIIT intervention. The identification of high and low responders indicates that junior badminton athletes do not adapt uniformly to standardized high-intensity training stimuli. Such variability may be influenced by differences in biological maturation, neuromuscular coordination, and prior training exposure, which are known to modulate responsiveness to high-intensity exercise during adolescence [22, 27, 28]. From a practical perspective, distinguishing responder profiles enables coaches to move beyond uniform conditioning prescriptions and adopt more individualized training strategies.

Low responders may require adjustments in training volume, recovery duration, or movement complexity to optimize adaptation, whereas high responders may benefit from progressive overload to further enhance sport-specific movement efficiency and intermittent endurance [28, 29]. This individualized approach aligns with contemporary long-term athlete development frameworks, which emphasize personalized progression and injury risk reduction during sensitive developmental periods in youth sports [22, 33]. Therefore, the responder-based findings extend beyond descriptive classification and offer a practical framework for optimizing badminton-specific conditioning in junior athletes.

Limitations of the study

Several limitations should be acknowledged. The study focused on short-term adaptations and did not assess long-term retention or transfer to competitive match outcomes. In addition, direct measures of neuromuscular or metabolic mechanisms were not included. Future research should integrate biomechanical analyses, muscle activation measures, and match-play performance indicators to further elucidate the pathways linking endurance and agility adaptations. Longitudinal studies examining different competitive levels and age groups would enhance the generalizability of the findings.

Conclusions

The findings of this controlled trial indicate that an 8-week badminton-specific high-intensity interval training (BS-HIIT) program is associated with greater improvements in agility and intermittent endurance compared with conventional conditioning in junior badminton athletes. The larger gains observed in badminton-specific agility performance and Yo-Yo IR1 outcomes suggest an enhanced ability to sustain repeated high-intensity actions while maintaining efficient sport-specific movement patterns. Moreover, the significant relationship between changes in intermittent endurance and agility highlights the integrative nature of physiological and neuromuscular adaptations induced by sport-specific HIIT. From an applied perspective, BS-HIIT represents a practical and time-efficient conditioning approach that can be incorporated into regular training schedules to improve key physical capacities relevant to competitive badminton without increasing overall training volume.

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Conflict of Interest

The authors report no conflict of interest.

References

1. Kosack MH, Staiano W, Folino R, Hansen MB, Lønbro S. The Acute Effect of Mental Fatigue on Badminton Performance in Elite Players. *International Journal of Sports Physiology and Performance*, 2020;15(5): 632–638. https://doi.org/10.1123/ijspp.2019-0361
2. Phomsoupha M, Laffaye G. The Science of Badminton: Game Characteristics, Anthropometry, Physiology, Visual Fitness and Biomechanics. *Sports Medicine*, 2015;45(4): 473–495. https://doi.org/10.1007/s40279-014-0287-2
3. Abian-Vicen J, Castanedo A, Abian P, Sampedro J. Temporal and notational comparison of badminton matches between men's singles and women's singles. *International Journal of Performance Analysis in Sport*, 2013;13(2): 310–320. https://doi.org/10.1080/24748668.2013.11868650
4. Shedge SS, Ramteke SU, Jaiswal PR. Optimizing Agility and Athletic Proficiency in Badminton Athletes Through Plyometric Training: A Review. *Cureus*, 2024;16(1):e52596. https://doi.org/10.7759/cureus.52596
5. Zhao Y, Zhu A, Zhang S, Zhang Y. Comparison of the temporal and technical-tactical characteristics in badminton men's singles under different competition formats. *Frontiers in Psychology*, 2025;16: 1634776. https://doi.org/10.3389/fpsyg.2025.1634776
6. Green R, West AT, Willems MET. Notational Analysis and Physiological and Metabolic Responses of Male Junior Badminton Match Play. *Sports*, 2023;11(2): 35. https://doi.org/10.3390/sports11020035
7. Edel A, Vuong J, Kaufmann S, Hoos O, Wiewelhove T, Ferrauti A. Metabolic profile in elite badminton match play and training drills. *European Journal of Sport Science*, 2024;24(11): 1639–1652. https://doi.org/10.1002/ejsc.12196
8. Fuchs M, Faude O, Wegmann M, Meyer T. Critical Evaluation of a Badminton-Specific Endurance Test. *International Journal of Sports Physiology and Performance*, 2014;9(2): 249–255. https://doi.org/10.1123/ijspp.2012-0387
9. Yue F, Wang Y, Yang H, Zhang X. Effects of high-intensity interval training on aerobic and anaerobic capacity in olympic combat sports: a systematic review and meta-analysis. *Frontiers in Physiology*, 2025;16: 1576676. https://doi.org/10.3389/fphys.2025.1576676
10. Liu Y, Abdullah BB, Abu Saad HB. Effects of high-intensity interval training on strength, speed, and endurance performance among racket sports players: A systematic review. Andreato LV (ed.) *PLOS ONE*, 2024;19(1): e0295362. https://doi.org/10.1371/journal.pone.0295362

11. Stöggl TL, Strepp T, Wiesinger HP, Haller N. A training goal-oriented categorization model of high-intensity interval training. *Frontiers in Physiology*, 2024;15: 1414307. https://doi.org/10.3389/fphys.2024.1414307
12. Milanović Z, Sporiš G, Weston M. Effectiveness of High-Intensity Interval Training (HIT) and Continuous Endurance Training for VO2max Improvements: A Systematic Review and Meta-Analysis of Controlled Trials. *Sports Medicine*, 2015;45(10): 1469–1481. https://doi.org/10.1007/s40279-015-0365-0
13. Hammami M, Gaamouri N, Ramirez-Campillo R, Shephard RJ, Bragazzi NL, Chelly MS, et al. Effects of high-intensity interval training and plyometric exercise on the physical fitness of junior male handball players. *European Review for Medical and Pharmacological Sciences*, 2021;25(23): 7380–7389. https://doi.org/10.26355/eurrev_202112_27434
14. Mcleod JC, Currier BS, Lowisz CV, Phillips SM. The influence of resistance exercise training prescription variables on skeletal muscle mass, strength, and physical function in healthy adults: An umbrella review. *Journal of Sport and Health Science*, 2024;13(1): 47–60. https://doi.org/10.1016/j.jshs.2023.06.005
15. Stone MH, Hornsby WG, Suarez DG, Duca M, Pierce KC. Training Specificity for Athletes: Emphasis on Strength-Power Training: A Narrative Review. *Journal of Functional Morphology and Kinesiology*, 2022;7(4): 102. https://doi.org/10.3390/jfmk7040102
16. Jansen MGT, Huijgen BCH, Faber IR, Elferink-Gemser MT. Measuring Agility in Tennis, Badminton, and Squash: A Systematic Review. *Strength & Conditioning Journal*, 2021;43(6): 53-53–67. https://doi.org/10.1519/SSC.0000000000000640
17. Qin H, Qian S, Zhou Y. Comparing The Effects of Singles vs. Doubles High-Intensity On-Court Tennis Training and Regular High-Intensity Interval Training on Aerobic and Anaerobic Performance Adaptations: A Randomized, Parallel-Controlled Study. *Journal of Sports Science and Medicine*, 2026; 159–171. https://doi.org/10.52082/jssm.2026.159
18. Engel FA, Ackermann A, Chtourou H, Sperlich B. High-Intensity Interval Training Performed by Young Athletes: A Systematic Review and Meta-Analysis. *Frontiers in Physiology*, 2018;9: 1012. https://doi.org/10.3389/fphys.2018.01012
19. I Putu Astrawan, I Made Dhita Prianthara, I A Pascha Paramurthi. The effect of 20 repetitions badminton footwork training on increasing maximum oxygen volume (VO2Max). *Bravo's: Journal of Physical Education and Sport Science*, 2025;13(Special Issue 2): 400–407. https://doi.org/10.32682/bravos.v13si2/148
20. Iqbal M, Suhartini B, Ali, Graha S. Optimization of agility training programs for badminton athletes: a systematic review. *Int J Multicult Multirelig Underst.* 2024;11(6):114–128.
21. Hader K, Mendez-Villanueva A, Ahmaidi S, Williams BK, Buchheit M. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. *BMC Sports Science, Medicine and Rehabilitation*, 2014;6(1): 2. https://doi.org/10.1186/2052-1847-6-2
22. Mujika I, Halson S, Burke LM, Balagué G, Farrow D. An Integrated, Multifactorial Approach to Periodization for Optimal Performance in Individual and Team Sports. *International Journal of Sports Physiology and Performance*, 2018;13(5): 538–561. https://doi.org/10.1123/ijspp.2018-0093
23. Du Y, Fan Y. The Effect of Fatigue on Postural Control and Biomechanical Characteristic of Lunge in Badminton Players. *Bioengineering*, 2023;10(3): 301. https://doi.org/10.3390/bioengineering10030301
24. Xu Y, Xu N, Wang R, Li W, Ho IMK, Poon ETC, et al. Relationships and agreement between Yo-Yo intermittent recovery test level 1 performance and laboratory VO_{2max} in adolescent male soccer players: roles of maturity status, playing position, and running economy. *Annals of Human Biology*, 2025;52(1): 2566327. https://doi.org/10.1080/03014460.2025.2566327
25. Abián-Vicén J, Bravo-Sánchez A, Abián P. AIR-BT, a new badminton-specific incremental easy-to-use test. Cè E (ed.) *PLOS ONE*, 2021;16(9): e0257124. https://doi.org/10.1371/journal.pone.0257124
26. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo Intermittent Recovery Test: A Useful Tool for Evaluation of Physical Performance in Intermittent Sports. *Sports Medicine*, 2008;38(1): 37–51. https://doi.org/10.2165/00007256-200838010-00004
27. Malina RM, Rogol AD, Cumming SP, Coelho E Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine*, 2015;49(13): 852–859. https://doi.org/10.1136/bjsports-2015-094623
28. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise*, 2009;41(1): 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278
29. De Oliveira F, Paz GA, Corrêa Neto VG, Alvarenga R, Marques Neto SR, Willardson JM, et al. Effects of Different Recovery Modalities on Delayed Onset Muscle Soreness, Recovery Perceptions, and Performance Following a Bout of High-Intensity Functional Training. *International Journal of Environmental Research and Public Health*, 2023;20(4): 3461. https://doi.org/10.3390/ijerph20043461
30. Buchheit M, Laursen PB. High-Intensity Interval Training, Solutions to the Programming Puzzle: Part I: Cardiopulmonary Emphasis. *Sports Medicine*, 2013;43(5): 313–338. https://doi.org/10.1007/s40279-013-0029-x
31. Harriss D, Atkinson G. Ethical Standards in Sport and Exercise Science Research: 2016 Update. *International Journal of Sports Medicine*, 2015;36(14): 1121–1124.https://doi.org/10.1055/s-0035-1565186
32. Batterham AM, Hopkins WG. The Case for Magnitude-based Inference. *Medicine & Science in Sports & Exercise*, 2015;47(4): 885. https://doi.org/10.1249/MSS.0000000000000551
33. Özer Ö, Soslu R, Uyhan O, Devrilmez M, Devrilmez E. Specific change of direction test for badminton players: badminton shuttle run agility test. *Physical Education of Students*, 2025;29(6): 457–465.

https://doi.org/10.15561/20755279.2025.0603
34. Zaidan AG, Pitriani P, Tafaqur M. The effect of shadow training using a racket and shadow training using a shuttlecock on the agility improvement of athletes in badminton. *Jorpres (Jurnal Olahraga Prestasi)*, 2024;20(1): 1–8. https://doi.org/10.21831/jorpres.v20i1.38956
35. Tibana R, De Sousa N, Cunha G, Prestes J, Fett C, Gabbett T, et al. Validity of Session Rating Perceived Exertion Method for Quantifying Internal Training Load during High-Intensity Functional Training. *Sports*, 2018;6(3): 68. https://doi.org/10.3390/sports6030068
36. D Egan A, B Winchester J, Foster C, R McGuigan M. Using Session RPE to Monitor Different Methods of Resistance Exercise. *Journal of Sports Science & Medicine*, 2006;5(2): 289–295.
37. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Frontiers in Neuroscience*, 2017;11: 612. https://doi.org/10.3389/fnins.2017.00612
38. Macedo AG, Almeida TAF, Massini DA, De Oliveira DM, Espada MC, Robalo RAM, et al. Load Monitoring Methods for Controlling Training Effectiveness on Physical Conditioning and Planning Involvement: A Narrative Review. *Applied Sciences*, 2024;14(22): 10465. https://doi.org/10.3390/app142210465
39. McCabe LH, Greer BD. Evaluations of heart rate during functional analyses of destructive behavior. *Journal of Applied Behavior Analysis*, 2023;56(4): 777–786. https://doi.org/10.1002/jaba.1019
40. Schneider C, Wiewelhove T, McLaren SJ, Röleke L, Käsbauer H, Hecksteden A, et al. Monitoring training and recovery responses with heart rate measures during standardized warm-up in elite badminton players. Mourot L (ed.) *PLOS ONE*, 2020;15(12): e0244412. https://doi.org/10.1371/journal.pone.0244412
41. Jensen MM, Pedersen HE, Clemmensen KKB, Ekblond TS, Ried-Larsen M, Færch K, et al. Associations Between Physical Activity and Gastrointestinal Transit Times in People with Normal Weight, Overweight, and Obesity. *The Journal of Nutrition*, 2024;154(1): 41–48. https://doi.org/10.1016/j.tjnut.2023.06.005
42. Silvino VO, Batista MCC, Neto MM, Ribeiro ALB, Nascimento PPD, Barros EML, et al. Effect of a cajuína hydroelectrolytic drink on the physical performance and hydration status of recreational runners. *Current Research in Physiology*, 2024;7: 100119. https://doi.org/10.1016/j.crphys.2024.100119
43. Hung CH, Su CH, Wang D. The Role of High-Intensity Interval Training (HIIT) in Neuromuscular Adaptations: Implications for Strength and Power Development—A Review. *Life*, 2025;15(4): 657. https://doi.org/10.3390/life15040657
44. Suppiah PK, Joummy AJ, Samsir MdS, Mariappan M, Noordin H, Nor Azmi AMB. The Effects of High Intensity Functional Interval Training on Selected Fitness Components Among Young Badminton Players. In: Hassan MHA, Che Muhamed AM, Mohd Ali NF, Lian DKC, Yee KL, Safii NS, et al. (eds) *Enhancing Health and Sports Performance by Design*, Singapore: Springer Singapore; 2020. p. 42–53. https://doi.org/10.1007/978-981-15-3270-2_5
45. Hung SH, Serwa K, Rosenthal G, Eng JJ. Validity of heart rate measurements in wrist-based monitors across skin tones during exercise. Sbrollini A (ed.) *PLOS ONE*, 2025;20(2): e0318724. https://doi.org/10.1371/journal.pone.0318724
46. Piña IL, Apstein CS, Balady GJ, Belardinelli R, Chaitman BR, Duscha BD, et al. Exercise and Heart Failure: A Statement From the American Heart Association Committee on Exercise, Rehabilitation, and Prevention. *Circulation*, 2003;107(8): 1210–1225. https://doi.org/10.1161/01.CIR.0000055013.92097.40
47. Korivi M, Ghanta MK, Nuthalapati P, Natesh NS, Tang J, Bhaskar L. Influence of Exercise on Oxygen Consumption, Pulmonary Ventilation, and Blood Gas Analyses in Individuals with Chronic Diseases. *Life*, 2025;15(8): 1255. https://doi.org/10.3390/life15081255
48. Chua MT, Chow KM, Lum D, Tay AWH, Goh WX, Ihsan M, et al. Effectiveness of On-Court Resistive Warm-Ups on Change of Direction Speed and Smash Velocity during a Simulated Badminton Match Play in Well-Trained Players. *Journal of Functional Morphology and Kinesiology*, 2021;6(4): 81. https://doi.org/10.3390/jfmk6040081
49. Loureiro LDFB, De Freitas PB. Development of an Agility Test for Badminton Players and Assessment of Its Validity and Test–Retest Reliability. *International Journal of Sports Physiology and Performance*, 2016;11(3): 305–310. https://doi.org/10.1123/ijspp.2015-0189
50. Tan B, Wang E, Cao K, Xiao L, Luo L. Study and Design of Distributed Badminton Agility Training and Test System. *Applied Sciences*, 2023;13(2): 1113. https://doi.org/10.3390/app13021113
51. Ciocca G, Tessitore A, Tschan H. Agility and change-of-direction speed are two different abilities also during the execution of repeated trials and in fatigued conditions. Lavender AP (ed.) *PLOS ONE*, 2022;17(6): e0269810. https://doi.org/10.1371/journal.pone.0269810
52. Wang Y, Wang Q, Dong X, Yang J, Cai K, Chen D, et al. Effects of 10-week modified badminton curriculum on physical fitness and sustained attention in elementary school children. *Scientific Reports*, 2025;15(1): 43889. https://doi.org/10.1038/s41598-025-25718-6
53. Liu T, Shao M, Yin D, Li Y, Yang N, Yin R, et al. The effect of badminton training on the ability of same-domain action anticipation for adult novices: Evidence from behavior and ERPs. *Neuroscience Letters*, 2017;660: 6–11. https://doi.org/10.1016/j.neulet.2017.08.038
54. Aslam S, Habyarimana JDD, Bin SY. Neuromuscular adaptations to resistance training in elite versus recreational athletes. *Frontiers in Physiology*, 2025;16: 1598149. https://doi.org/10.3389/fphys.2025.1598149

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ORIGINAL ARTICLE

Age-related differences in physical fitness components of youth soccer players

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Abstract

Background and Study Aim: Soccer performance relies heavily on physical fitness components, including linear speed, explosive power, change-of-direction ability, and aerobic endurance. During early adolescence, these attributes develop alongside biological maturation and systematic training exposure, which may differentially influence performance outcomes across age groups. Despite the widespread use of standardized field-based tests to assess physical fitness in youth soccer players, the manifestation of age-related differences between closely spaced categories remains a matter of practical interest. This study aimed to investigate differences in selected physical fitness components between U13 and U15 youth soccer players using standardized field-based tests.

Material and Methods: A cross-sectional comparative design was employed with 36 male youth soccer players (U13: n = 18, mean age 12.7 ± 0.4 years; U15: n = 18, mean age 14.6 ± 0.5 years) from organized training programs at Nakhchivan State University. All participants had at least two years of systematic soccer training and were free from recent injuries. Physical fitness was assessed using the 30 m sprint test (linear speed), the standing long jump (lower-body explosive power), the Illinois agility test (change-of-direction ability), and the Yo-Yo Intermittent Recovery Test Level 1 (aerobic endurance). Data were analyzed using independent-samples t-tests and Cohen's d effect sizes ($p < 0.05$). The study adhered to the Declaration of Helsinki. Informed consent was obtained from parents or guardians, and participants provided assent.

Results: Statistically significant differences were found between groups in all measured variables ($p < 0.001$). U15 players outperformed U13 players with faster 30 m sprint times (4.41 ± 0.27 s vs. 4.82 ± 0.31 s, t = 4.12, d = 1.38), greater standing long jump distances (1.95 ± 0.18 m vs. 1.72 ± 0.15 m, t = −3.89, d = 1.40), quicker Illinois agility test times (16.93 ± 0.69 s vs. 18.21 ± 0.74 s, t = 5.06, d = 1.45), and higher Yo-Yo IR1 distances (1420 ± 260 m vs. 910 ± 210 m, t = −6.01, d = 2.15). All effect sizes were large.

Conclusions: The results demonstrate clear age-related differences in physical fitness between U13 and U15 youth soccer players. Older players showed superior sprint speed, explosive power, agility, and aerobic endurance. These findings reflect the combined influence of biological maturation and accumulated training experience during early adolescence. The study highlights the importance of age-specific and developmentally appropriate training programs in youth soccer. Regular assessment of physical fitness using standardized field-based tests may support evidence-based training planning, performance monitoring, and long-term athlete development in youth soccer environments.

Keywords: youth soccer, age-related differences, sprint performance, agility, aerobic endurance, physical fitness

Introduction

Physical fitness represents one of several key factors influencing performance in youth soccer, contributing to players' capacity to meet the physical and technical demands of training and competition across different stages of development. During adolescence, soccer-specific performance is shaped by a complex interaction of growth-related changes, neuromuscular development, and accumulated training stimuli, which together affect speed, power, agility, and endurance capacities. These components do not develop uniformly, and their expression may vary substantially between age groups even within relatively narrow chronological ranges. Consideration of how multiple physical fitness attributes manifest across adjacent youth categories is important for interpreting performance differences and aligning training demands with players' developmental characteristics.

Building on this perspective, soccer is characterized by its intermittent high-intensity nature, requiring players to repeatedly perform actions such as sprinting, jumping, accelerating, decelerating, and changing direction throughout a match [1, 2]. As a result, success in soccer depends not only on technical and tactical skills but also on well-developed physical fitness components, including speed, strength, power, agility, and

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aerobic endurance [1, 3, 4]. In youth soccer, the development of these physical attributes plays an important role in both short-term performance and long-term athlete development [5].

During childhood and adolescence, players experience rapid physiological, neuromuscular, and morphological changes associated with growth and biological maturation [6, 7]. These changes strongly influence physical performance and may lead to substantial differences among players across age categories [5, 8]. Consequently, consideration of age-related variations in physical fitness is essential for coaches, physical education teachers, and sport scientists who aim to design appropriate training programs and to ensure healthy and sustainable development in young soccer players [9].

Youth soccer development systems are typically organized by chronological age (e.g., U13, U15, U17). While this classification is practical for competition and training organizations, it does not always reflect individual differences in biological maturation [7]. Nevertheless, age-group-based analysis remains a widely used and valuable approach for examining developmental trends in physical fitness and performance [5, 10]. Research focusing on age-related differences can provide reference values that help practitioners evaluate player development and identify appropriate training priorities for each age group [8].

Previous research has consistently shown that older youth soccer players tend to perform better physically than their younger counterparts [5, 11]. Improvements in sprint speed, muscular power, agility, and aerobic endurance have been reported with increasing age. These changes are largely attributed to maturation-related increases in muscle mass, neuromuscular coordination, and cardiovascular capacity [12, 13]. In addition, older players generally have greater exposure to structured training programs, which further enhances their physical fitness [9, 14].

Speed and agility are particularly important physical attributes in soccer, as decisive game actions such as winning duels, creating space, and reacting to opponents often occur within very short time frames [1, 15]. Studies have indicated that sprint performance over short distances and change-of-direction ability improve markedly during early and mid-adolescence [12, 13]. Similarly, lower-body explosive power, commonly assessed through jumping tests, shows significant age-related progression. It is closely associated with sprinting and agility performance in youth soccer players [16].

Aerobic endurance is another key component of soccer performance, as players must sustain repeated high-intensity efforts throughout a match [3, 17]. Field-based endurance tests, such as the Yo-Yo Intermittent Recovery Test Level 1, have been widely used to assess soccer-specific aerobic capacity in youth players [11, 17]. The Yo-Yo IR1 test is particularly relevant for soccer because it mimics the intermittent nature of match play. It has also been shown to discriminate between players of different competitive levels and age categories [15, 18].

Despite the growing body of literature on youth soccer performance, several gaps remain. Many studies have focused on elite academy players from well-established soccer nations, whereas evidence from other soccer systems and diverse regional contexts is less extensive [4, 18]. In addition, some studies have examined broad age ranges without providing detailed comparisons between closely related age groups, such as U13 and U15. These categories represent critical stages of physical and biological development [5, 17].

From a practical perspective, a lack of age-specific reference data may lead coaches to apply similar training loads and physical demands across different age groups. This approach may increase the risk of overtraining or injury in younger players [9]. Conversely, insufficient physical stimulus may limit performance development in older players. Therefore, research that identifies age-related differences in physical fitness can support more individualized and developmentally appropriate training approaches [14, 19].

In physical education and youth sport contexts, empirical evidence on physical fitness development can inform curriculum design and assessment practices. Information on how physical performance evolves across age categories allows educators to set realistic expectations and to promote positive and developmentally appropriate experiences in sport participation [9]. Such evidence also aligns with the broader framework of long-term athlete development, which emphasizes gradual progression, age-appropriate training, and the avoidance of early specialization [10].

Within this framework, comparative research examining age-related differences in physical fitness among youth soccer players provides a practical basis for structuring training models, assessment strategies, and performance monitoring systems across age groups [20]. Evidence derived from standardized field-based testing protocols supports informed decision-making in both coaching practice and educational settings, including higher sports education institutions involved in youth sport development.

Analysis of research findings has shown that physical fitness components in youth soccer develop progressively with age, reflecting the combined influence of biological maturation and systematic training exposure. Researchers emphasize that attributes such as speed, power, agility, and aerobic endurance play a critical role in shaping performance during key developmental stages of adolescence. At the same time, the multifactorial nature of physical

development and the close proximity of certain age categories highlight unresolved aspects related to the interpretation of age-related differences and their practical implications for training and assessment. This context points to the need for the search for more effective approaches to evaluating physical fitness and informing training organization in youth soccer. This context points to the need for the search for more effective approaches to evaluating physical fitness and informing training organization in youth soccer. Within this framework, the present study examined differences in selected physical fitness components between U13 and U15 youth soccer players using standardized field-based tests.

Materials and Methods

Participants

A total of 36 male youth soccer players volunteered for the study. Participants were divided into two age groups based on chronological age: U13 (n = 18; mean age 12.7 ± 0.4 years) and U15 (n = 18; mean age 14.6 ± 0.5 years). All participants were actively involved in organized soccer training and competition at the time of the study and had at least two years of systematic training experience. Players trained three to four times per week and regularly participated in weekend matches.

The inclusion criteria for participation were as follows: (a) registration as an active soccer player in a youth training program, (b) absence of musculoskeletal injury or illness during the three months preceding the study, and (c) regular attendance at training sessions. Players who reported recent injuries or medical conditions that could affect physical performance were excluded from the study.

Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki for research involving human participants. Prior to data collection, players and their parents or legal guardians were informed about the study purpose, procedures, potential risks, and benefits. Written informed consent was obtained from parents or guardians, and verbal assent was obtained from all participants. Participation was voluntary, and players were free to withdraw from the study at any time without penalty.

Research Design

This study employed a cross-sectional comparative research design to examine age-related differences in selected physical fitness components of youth soccer players. A cross-sectional approach was considered appropriate because it allows comparison of physical performance characteristics across age groups at a single point in time. This design is commonly used in youth sport and physical education research. It is suitable for identifying developmental differences associated with chronological age.

Testing Procedures

Physical fitness testing was conducted on an outdoor soccer field under standardized conditions. All tests were completed during the competitive season to ensure that players were in regular training condition. Testing sessions were scheduled in the afternoon to coincide with the players' usual training time. Environmental conditions, including temperature and surface type, were consistent for all participants.

Prior to testing, all players completed a standardized warm-up lasting approximately 15 minutes. The warm-up included light jogging, dynamic stretching exercises, mobility drills, and progressive acceleration runs. Adequate recovery time was provided between tests to minimize the effects of fatigue on performance outcomes.

Physical Fitness Tests

30 m Sprint Test. Linear sprint speed was assessed using the 30 m sprint test. Players performed two maximal sprints over a 30 m distance from a standing start. Electronic timing gates were installed at the start and finish lines to ensure accurate timing. The best time recorded from the two trials was used for statistical analysis. A rest period of at least three minutes was provided between trials.

Standing Long Jump. Lower-body explosive power was evaluated using the standing long jump test. Participants stood behind a take-off line with their feet shoulder-width apart and performed a maximal forward jump using a two-foot take-off. Arm swing was permitted. Two trials were performed, and the longest distance achieved was recorded to the nearest centimeter.

Illinois Agility Test. Change-of-direction speed and agility were assessed using the Illinois agility test. The test setup consisted of a rectangular course with cones placed according to standardized guidelines. Players were instructed to complete the course as quickly as possible while following the designated running pattern. Time was recorded using electronic timing gates. Two trials were conducted with adequate recovery, and the fastest time was selected for analysis.

Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) [17]. Aerobic endurance capacity was assessed using the Yo-Yo Intermittent Recovery Test Level 1. The test consists of repeated 20 m shuttle runs performed at progressively increasing speeds and interspersed with 10 s active recovery periods. An audio signal controlled the running pace. The test was terminated when a player failed to reach the finish line in time with the audio signal on two occasions. The total distance covered was recorded and used as the performance indicator.

Test Order. To minimize fatigue effects, tests were administered in the following order: 30 m sprint, standing long jump, Illinois agility test, and Yo-Yo IR1. This order was selected to ensure that maximal anaerobic performance tests were completed before the endurance assessment. All tests were administered by the same research team using standardized protocols to enhance reliability. Prior to data collection, players were familiarized with all test procedures.

Statistical Analysis

Data were analyzed using SPSS statistical software. Descriptive statistics, including the mean and standard deviation (mean ± SD), were calculated for all variables. The normality of data distribution was assessed using the Shapiro–Wilk test. Independent-samples t-tests were conducted to examine differences between U13 and U15 players for each physical fitness variable. The level of statistical significance was set at $p < 0.05$. Effect sizes (Cohen's d) were calculated to determine the magnitude of the observed differences between age groups.

Results

Descriptive statistics and results of between-group comparisons for all measured physical fitness variables in U13 and U15 soccer players are presented in Table 1.

Table 1 summarizes the descriptive statistics for all measured physical fitness variables in U13 and U15 players. Differences in central tendency and variability were observed between the two age groups across all tested variables.

For sprint performance, the mean 30 m sprint time for U13 players was 4.82 ± 0.31 s, whereas U15 players recorded a mean time of 4.41 ± 0.27 s. Standing long jump performance showed a mean distance of 1.72 ± 0.15 m in the U13 group and 1.95 ± 0.18 m in the U15 group. In the Illinois agility test, U13 players completed the test in 18.21 ± 0.74 s, while U15 players completed it in 16.93 ± 0.69 s.

Aerobic endurance performance, assessed using the Yo-Yo Intermittent Recovery Test Level 1, indicated that U13 players covered a mean distance of 910 ± 210 m. In contrast, U15 players covered 1420 ± 260 m.

Independent-samples t-test results demonstrated statistically significant differences between U13 and U15 players for all measured physical fitness variables ($p < 0.05$). Significant between-group differences were observed for the 30 m sprint ($t = 4.12$, $p < 0.001$), standing long jump ($t = -3.89$, $p < 0.001$), and Illinois agility test ($t = 5.06$, $p < 0.001$). Analysis of Yo-Yo IR1 performance also revealed a statistically significant difference between age groups ($t = -6.01$, $p < 0.001$).

Effect size analysis using Cohen's d revealed large effects for all variables. Effect sizes were 1.38 for the 30 m sprint, 1.40 for the standing long jump, 1.45 for the Illinois agility test, and 2.15 for the Yo-Yo IR1. These values indicate substantial differences between the age groups.

Discussion

The purpose of this study was to examine age-related differences in selected physical fitness components between U13 and U15 youth soccer players. The results demonstrated statistically significant differences between the two age groups across all measured variables, including sprint speed, lower-body explosive power, agility, and aerobic endurance. These findings are consistent with research by Deprez et al. [5] and Mirkov et al. [20], who reported age-related improvements in physical performance indicators among youth soccer players. Similar age-related trends in sprinting ability, agility, and intermittent endurance have also been reported in recent studies of youth soccer players [21, 22]. From a developmental perspective, age-specific reference values can support more accurate interpretation of physical performance during key stages of youth soccer progression, as also indicated by Aliyev et al. [10].

In the present study, sprint performance differed between U13 and U15 players, with faster sprint times observed in the older age group. Similar age-related improvements in linear sprint speed have been reported in previous research involving youth soccer players [12, 13]. Earlier studies have indicated that sprint ability tends to improve during adolescence in association with neuromuscular maturation, increases in muscle mass, and improvements in motor coordination [6, 7]. In addition, findings from youth soccer research suggest that short-distance sprint performance is influenced by both biological maturation and accumulated training exposure, which may contribute to performance differences across age groups [1, 15]. Comparable age-related patterns in sprint performance have also been

Table 1. Comparison of physical fitness variables between U13 and U15 soccer players

Variable	U13 (Mean ± SD)	U15 (Mean ± SD)	t	p
30 m sprint (s)	4.82 ± 0.31	4.41 ± 0.27	4.12	< 0.001
Standing long jump (m)	1.72 ± 0.15	1.95 ± 0.18	−3.89	< 0.001
Illinois agility test (s)	18.21 ± 0.74	16.93 ± 0.69	5.06	< 0.001
Yo-Yo IR1 (m)	910 ± 210	1420 ± 260	−6.01	< 0.001

described in recent cross-sectional studies of youth soccer players with similar training ages [22, 23].

Similarly, standing long jump performance differed between U13 and U15 players, with higher values observed in the older age group. Previous studies of youth soccer players have reported similar age-related patterns in jump performance and lower-body explosive power during adolescence [12, 16, 23]. These studies have associated age-related changes in muscular power with maturation-related factors, including increases in muscle cross-sectional area, neuromuscular adaptations, and more effective utilization of the stretch-shortening cycle [12]. In addition, research examining the influence of biological maturation on physical performance adaptations has indicated that strength- and power-related outcomes may develop differently across maturation stages during adolescence [24].

Agility performance, assessed using the Illinois agility test, differed between U13 and U15 players, with shorter completion times observed in the older age group in the present study. Similar age-related differences in change-of-direction performance have been reported in youth soccer players, with improvements commonly observed alongside increasing age and training experience [20]. Research examining agility and change-of-direction tasks in adolescent soccer players has indicated that these performance changes are associated with maturation-related developments and accumulated sport-specific training exposure, as reflected in the relationships between sprinting, jumping, and change-of-direction performance [1, 25]. In addition, recent studies analyzing sprinting and change-of-direction performance across youth age categories have reported progressive improvements in agility-related outcomes during adolescence [23].

In the present study, aerobic endurance, assessed using the Yo-Yo Intermittent Recovery Test Level 1, differed between U13 and U15 players, with greater distances covered by the older age group. Similar age-related increases in intermittent endurance capacity have been reported in youth soccer players, with older adolescents typically demonstrating higher Yo-Yo IR1 performance than younger age groups [3, 18]. Normative data derived from adolescent male athletes show that Yo-Yo IR1 distances increase progressively with age, supporting the interpretation of developmental changes in aerobic endurance during adolescence [26]. In addition, research conducted in youth football players has demonstrated a close relationship between aerobic capacity and Yo-Yo IR1 performance, indicating that higher aerobic fitness is associated with greater intermittent endurance distances [27]. The Yo-Yo IR1 test has been widely recognized as a valid and reliable measure of soccer-specific aerobic fitness, and its sensitivity to age-related differences has been consistently reported in youth soccer research [11, 17].

In the present study, the observed between-group differences may reflect not only age-related maturation but also differences in accumulated training exposure. Previous studies have described biological maturation as an important factor associated with physical performance development during adolescence [12, 13]. In addition, research in youth soccer has indicated that older age groups generally have longer training histories, higher weekly training volumes, and greater exposure to competitive demands than younger players, which may contribute to differences in physical fitness outcomes [9, 10, 14]. Such accumulated soccer-specific training has been linked to progressive improvements in performance components requiring repeated high-intensity actions and intermittent efforts, including sprinting and intermittent endurance measures [1, 3, 9, 14].

From an institutional perspective, the organization of youth training programmes and the selection of physical assessment tools are shaped by strategic planning and management practices within sports education institutions, which influence how training content, load progression, and performance monitoring are implemented across age groups [19]. Such organizational frameworks determine the consistency and specificity of training exposure during different stages of youth development.

At the individual level, maturation-related neuromuscular adaptations occurring during adolescence, including changes in motor unit recruitment, firing frequency, and intermuscular coordination, have been associated with improvements in the execution of rapid and explosive movements [12, 13, 28]. Recent research in youth soccer has shown that training interventions targeting neuromuscular function are associated with improvements in sprinting, jumping, and change-of-direction performance, supporting the role of neuromuscular control and muscle–tendon adaptations during adolescence [29]. In addition, evidence examining the influence of maturation stage on physical fitness attributes indicates that age- and maturation-related differences contribute to variability in speed, power, and agility outcomes in youth athletes [30]. These adaptations are particularly relevant for performance tasks such as sprinting, jumping, and agility, which require rapid force production and efficient motor control [7, 20, 31].

Taken together, the interaction between structured training exposure within organized youth development systems and maturation-related physiological adaptations provides a coherent framework for interpreting the age-related improvements in speed, power, agility, and intermittent endurance observed in older youth soccer players.

Study Limitations and Future Directions

This study has several limitations that should be considered when interpreting the findings. The cross-sectional design does not allow causal inferences regarding the effects of age, maturation, or training on physical fitness development. In addition, biological maturation was not directly assessed, which may have influenced the observed differences between age groups. The sample size was relatively small and limited to male youth soccer players, which may restrict the generalizability of the results.

Future research may benefit from longitudinal designs that track physical fitness development across multiple age categories while accounting for maturation status and training load. Examination of players from different training environments and developmental settings could further extend the applicability of the findings. Such approaches may contribute to more refined age- and development-specific training and assessment frameworks in youth soccer.

Practical Implications

The findings of this study have several practical implications for youth soccer coaching and training organization. Clear differences in physical fitness between U13 and U15 players indicate that training programs should be adapted to players' developmental characteristics rather than applying uniform physical demands across age groups. Age-specific planning may support safer and more effective progression of physical abilities during adolescence.

For younger players (U13), training should prioritize the development of fundamental movement skills, coordination, balance, and basic speed mechanics. Emphasis on technical quality, correct movement execution, and positive training experiences is appropriate at this stage. Strength and power activities may be introduced using bodyweight or low external loads, with a focus on technique rather than maximal output, while excessive high-intensity conditioning should be avoided.

For older players (U15), training programs may gradually incorporate more structured physical conditioning elements. Greater emphasis can be placed on sprint performance, explosive power, agility, and intermittent endurance, reflecting increased tolerance to training load associated with maturation and accumulated training experience. Progression should remain gradual, and individual responses to training should be monitored.

Regular use of standardized field-based physical fitness tests can support systematic monitoring of player development. Periodic assessment allows practitioners to track changes over time, identify individual strengths and limitations, and adjust training content accordingly. Such an approach may also assist talent development systems in establishing age-appropriate benchmarks and supporting long-term player development through balanced integration of physical, technical, and tactical training.

Conclusions

The findings of this study indicate that physical fitness characteristics in youth soccer players differ systematically between U13 and U15 age groups during early adolescence. Statistically significant differences were observed across all assessed variables, including sprint speed, lower-body explosive power, agility, and aerobic endurance, with higher values consistently recorded in the older age group.

These results reflect age-related changes associated with biological maturation and accumulated training exposure, highlighting the non-uniform development of physical fitness components during adolescence. The observed differences emphasize that even relatively small age gaps may be accompanied by substantial variation in physical performance capacities among youth soccer players.

Overall, the study contributes to a clearer characterization of age-related physical fitness profiles in youth soccer and supports the use of standardized field-based testing to document developmental trends across age categories. Such evidence may assist in improving the interpretation of physical performance outcomes within youth soccer development systems.

Conflict of interests

The authors declare that there is no conflict of interests.

References

1. Stølen T, Chamari K, Castagna C, Wisløff U. Physiology of Soccer: An Update. *Sports Medicine*, 2005;35(6): 501–536. https://doi.org/10.2165/00007256-200535060-00004
2. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, 2012;30(7): 625–631. https://doi.org/10.1080/02640414.2012.665940
3. Castagna C, Manzi V, Impellizzeri F, Weston M, Barbero Alvarez JC. Relationship Between Endurance Field Tests and Match Performance in Young Soccer Players. *Journal of Strength and Conditioning Research*, 2010;24(12): 3227–3233. https://doi.org/10.1519/JSC.0b013e3181e72709
4. Chamari K, Hachana Y, Ahmed YB, Galy O, Sghaïer F, Chatard JC, et al. Field and laboratory testing in young elite soccer players. *British Journal of Sports Medicine*, 2004;38(2): 191–196. https://doi.org/10.1136/bjsm.2002.004374
5. Deprez D, Fransen J, Boone J, Lenoir M, Philippaerts R, Vaeyens R. Characteristics of high-level youth soccer players: variation by playing position. *Journal of Sports Sciences*, 2015;33(3): 243–254. https://doi.org/10.1080/02640414.2014.934707
6. Malina RM, Bouchard C, Bar-Or O. *Growth, maturation, and physical activity*. Human Kinetics; 2004.
7. Malina RM, Rogol AD, Cumming SP, Coelho E Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine*, 2015;49(13): 852–859. https://doi.org/10.1136/bjsports-2015-094623
8. Mendez-Villanueva A, Buchheit M, Simpson B, Bourdon P. Match Play Intensity Distribution in Youth Soccer. *International Journal of Sports Medicine*, 2012;34(02): 101–110. https://doi.org/10.1055/s-0032-1306323
9. Vaeyens R, Lenoir M, Williams AM, Philippaerts RM. Talent Identification and Development Programmes in Sport: Current Models and Future Directions. *Sports Medicine*, 2008;38(9): 703–714. https://doi.org/10.2165/00007256-200838090-00001
10. Williams AM, Ford PR, Drust B. Talent identification and development in soccer since the millennium. *Journal of Sports Sciences*, 2020;38(11–12):1199–1210. https://doi.org/10.1080/02640414.2020.1766647
11. Krustrup P, Mohr M, Amstrup T, Rysgaard T, Johansen J, Steensberg A, et al. The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity: *Medicine & Science in Sports & Exercise*, 2003;35(4): 697–705. https://doi.org/10.1249/01.MSS.0000058441.94520.32
12. Impellizzeri F, Rampinini E, Castagna C, Bishop D, Ferrari Bravo D, Tibaudi A, et al. Validity of a Repeated-Sprint Test for Football. *International Journal of Sports Medicine*, 2008;29(11): 899–905. https://doi.org/10.1055/s-2008-1038491
13. Buchheit M, Laursen PB. High-Intensity Interval Training, Solutions to the Programming Puzzle: Part I: Cardiopulmonary Emphasis. *Sports Medicine*, 2013;43(5): 313–338. https://doi.org/10.1007/s40279-013-0029-x
14. Bompa TO, Buzzichelli C. *Periodisation: Theory and methodology of training*. 6th ed. Human Kinetics; 2019.
15. Haugen TA, Tønnessen E, Seiler S. Speed and Countermovement-Jump Characteristics of Elite Female Soccer Players, 1995–2010. *International Journal of Sports Physiology and Performance*, 2012;7(4): 340–349. https://doi.org/10.1123/ijspp.7.4.340
16. Ziv G, Lidor R. Vertical jump in female and male basketball players—A review of observational and experimental studies. *Journal of Science and Medicine in Sport*, 2010;13(3): 332–339. https://doi.org/10.1016/j.jsams.2009.02.009
17. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo Intermittent Recovery Test: A Useful Tool for Evaluation of Physical Performance in Intermittent Sports. *Sports Medicine*, 2008;38(1): 37–51. https://doi.org/10.2165/00007256-200838010-00004
18. Di Salvo V, Baron R, Tschan H, Calderon Montero F, Bachl N, Pigozzi F. Performance Characteristics According to Playing Position in Elite Soccer. *International Journal of Sports Medicine*, 2007;28(3): 222–227. https://doi.org/10.1055/s-2006-924294
19. Seymur Aliyev, Yusif Valiyev, Kifayat Huseynova, Taleh Khalilov. The Impact of Strategic Planning on Management in Higher Sports Education Institutions. *International Journal of Computational and Experimental Science and Engineering*, 2025;11(2). https://doi.org/10.22399/ijcesen.1417
20. Mirkov DM, Kukolj M, Ugarkovic D, J. Koprivica V, Jaric S. Development of Anthropometric and Physical Performance Profiles of Young Elite Male Soccer Players: A Longitudinal study. *Journal of Strength and Conditioning Research*, 2010;24(10): 2677–2682. https://doi.org/10.1519/JSC.0b013e3181e27245
21. Becerra Patiño BA, Montenegro Bonilla AD, Paucar-Uribe JD, Rada-Perdigón DA, Olivares-Arancibia J, Yáñez-Sepúlveda R, et al. Characterization of Fitness Profiles in Youth Soccer Players in Response to Playing Roles Through Principal Component Analysis. *Journal of Functional Morphology and Kinesiology*, 2025;10(1): 40. https://doi.org/10.3390/jfmk10010040
22. Kirmizigil B, Chauchat J. Age-Related Differences in Functional Capacity and Technical Performance in Youth Soccer Players With Similar Training Ages. *Journal of Basic and Clinical Health Sciences*, 2025;9(2): 395–403. https://doi.org/10.30621/jbachs.1646068
23. Zghal F, Rebai H, Colson SS, Samozino P, Rahmani A, Peyrot N, et al. Age-Related Differences in Jumping and Sprinting Performance and Force Production Capacities in Young Soccer Players. *European Journal of Sport Science*, 2025;25(10): e12301. https://doi.org/10.1002/ejsc.12301
24. Ferrini M, Asian-Clemente J, Bagattini G, Suarez-Arrones L. Effects of Maturation Status on Physical Performance Adaptations Following a Combined 7-Week Strength and Power Training Program in Elite Male Youth Soccer Players. *Applied Sciences*, 2025;15(21): 11505.

https://doi.org/10.3390/app152111505
25. Falces-Prieto M, González-Fernández FT, García-Delgado G, Silva R, Nobari H, Clemente FM. Relationship between sprint, jump, dynamic balance with the change of direction on young soccer players' performance. *Scientific Reports*, 2022;12(1): 12272. https://doi.org/10.1038/s41598-022-16558-9
26. Schmitz B, Pfeifer C, Kreitz K, Borowski M, Faldum A, Brand SM. Normative Yo-Yo Intermittent Recovery Level 1 and Yo-Yo Intermittent Endurance Level 1 test values of boys aged 9–16 years. *Journal of Science and Medicine in Sport*, 2019;22(9): 1030–1037. https://doi.org/10.1016/j.jsams.2019.05.016
27. Michailidis Y. The Relationship between Aerobic Capacity, Anthropometric Characteristics, and Performance in the Yo-Yo Intermittent Recovery Test among Elite Young Football Players: Differences between Playing Positions. *Applied Sciences*, 2024;14(8): 3413. https://doi.org/10.3390/app14083413
28. Lloyd RS, Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength & Conditioning Journal*, 2012;34(3): 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea
29. Zheng T, Kong R, Liang X, Huang Z, Luo X, Zhang X, et al. Effects of plyometric training on jump, sprint, and change of direction performance in adolescent soccer player: A systematic review with meta-analysis. Clemente FM (ed.) *PLOS One*, 2025;20(4): e0319548. https://doi.org/10.1371/journal.pone.0319548
30. Lin G, Chen J, Yan R, Deng B, Song W, Guan B, et al. Effects of Maturation Stage on Physical Fitness in Youth Male Team Sports Players After Plyometric Training: A Systematic Review and Meta-Analysis. *Sports Medicine - Open*, 2025;11(1): 97. https://doi.org/10.1186/s40798-025-00907-9
31. Myer GD, Faigenbaum AD, Ford KR, Best TM, Bergeron MF, Hewett TE. When to Initiate Integrative Neuromuscular Training to Reduce Sports-Related Injuries and Enhance Health in Youth?: *Current Sports Medicine Reports*, 2011;10(3): 155–166. https://doi.org/10.1249/JSR.0b013e31821b1442

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ORIGINAL ARTICLE

A comparative analysis of repetition speed development in Gyaku-Tsuki and Mae-Geri techniques in junior Kempo athletes

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Abstract

Background and Study Aim: Repetition speed of specific techniques represents a component of technical and tactical performance in striking-based combat sports. It is closely related to neuromuscular control, intersegmental coordination, and execution efficiency. The development of rapid, repeated, and precise motor actions is commonly addressed within training programs using various methodological approaches. Despite the application of different training methods, their relative effectiveness in enhancing repeated execution speed remains a matter of practical interest. The aim of this study was to comparatively analyze the development of repetition speed in Gyaku-Tsuki and Mae-Geri techniques in 10–12-year-old junior Kempo athletes following an athletics-based training intervention.

Material and Methods: The study included 24 male junior Kempo athletes aged 10–12 years. Participants were divided into an experimental group (n = 12) and a control group (n = 12). Assessments were conducted at two time points (T1 and T2). Repetition speed was evaluated using 10-second maximal execution tests for Gyaku-Tsuki and Mae-Geri. The Wittygate electronic timing system was employed. Statistical analysis included descriptive indicators, the Shapiro–Wilk test, the Mann–Whitney U test, and Levene's test. The significance level was set at $p < 0.05$.

Results: The experimental group showed greater improvements than the control group in both tests. For VRGT, the differences were favorable to the experimental group but did not reach statistical significance. In contrast, VRMG showed statistically significant improvements in the experimental group compared with the control group.

Conclusions: The results demonstrate that the introduction of athletics-based exercises into the training structure had a positive effect on VRGT and a significant effect on VRMG in junior athletes. These findings support the need for an integrative approach in combat sports training. In this approach, the development of repeated execution speed through athletic means is harmonized with the refinement of Kempo-specific techniques. This contributes to improved training efficiency and sports performance.

Keywords: neuromuscular adaptation, combat sports training, youth athletes, motor control, repeated actions, performance analysis

Introduction

Performance in combat sports is strongly influenced by the athlete's ability to execute specific motor actions rapidly and repetitively. At the same time, athletes must maintain a high level of neuromuscular control and technical precision. In combat disciplines such as Kempo, repetition speed of striking techniques represents a factor of technical and tactical efficiency. It influences both offensive capacity and the ability to adapt to the dynamic demands of competition. This component is particularly relevant in junior athletes. The early developmental period is characterized by increased neuromuscular plasticity, which is favorable for optimizing the frequency and continuity of technical executions.

Repetition speed reflects the capacity of the nervous system to coordinate successive neuromuscular activations within a limited time interval. This coordination allows the maintenance of a high execution rate without degradation of technical quality [1]. The specialized literature indicates that performance in rapid repetition tasks is influenced by training level, degree of movement automation, and the efficiency of recruitment and synchronization of motor units. These factors are particularly relevant under conditions of explosive and repetitive effort [1, 2]. In contact sports, actions follow one another rapidly and require continuous execution of specific techniques. Therefore, the development of repetition speed becomes a central objective of the neuromotor training process [1, 2]. This capacity enables athletes to maintain a high execution rhythm under repeated loading conditions without compromising technical control and neuromuscular efficiency.

Gyaku-Tsuki (VRGT) represents a relevant

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indicator of the athlete's ability to rapidly and repeatedly execute an upper-limb striking technique. This technique is characterized by linear, coordinated, and controlled movements [3]. The assessment of this test provided information regarding the efficiency of intersegmental coordination. It also reflected neuromuscular control of the upper kinetic chain and the capacity to maintain a high execution rhythm within a predetermined time interval [4]. Performance in the VRGT test reflects the level of movement automation and the efficiency of motor unit activation involved in explosive and repetitive actions.

As a complementary element, Mae-Geri (VRMG) provides information on the capacity for rapid repetitive execution of a lower-limb striking technique. This technique involves larger body segments and requires a higher level of coordination, postural stability, and neuromuscular control [5]. Successive executions in the VRMG test reflect the efficiency of integrating strength, speed, and coordination in repetitive actions. They are closely related to center-of-mass control and synchronized activation of the involved muscle chains [6].

Recent studies indicate that interventions oriented toward the development of execution speed and repetition capacity can lead to significant improvements in neuromotor performance in young athletes [7, 8]. However, data regarding technique-specific repetition speed adaptations for distinct techniques such as Gyaku-Tsuki and Mae-Geri remain limited, particularly among junior martial arts practitioners [9]. Previous research in martial arts has primarily addressed execution speed assessment or the development and validation of speed tests for techniques such as Gyaku-Tsuki and Mawashi or Mae-Geri. These studies were mainly conducted in karate-based contexts. They did not focus on repetition speed adaptations or comparative analyses in junior athletes [10, 11, 12]. In this context, the comparative analysis of repetition speed dynamics in the VRGT and VRMG tests allows a deeper understanding of how general neuromuscular adaptations transfer to the repetitive execution of Kempo-specific techniques. It also provides objective benchmarks for optimizing the training process and for the scientific substantiation of training programs oriented toward the development of neuromotor speed [13].

Analysis of research findings has shown that repetition speed is closely associated with neuromuscular coordination, movement automation, and the ability to sustain high technical performance under repeated execution conditions. Researchers emphasize that the development of this capacity plays a meaningful role in optimizing technical and tactical efficiency, particularly in striking-based combat sports during the early stages of athletic development. At the same time, unresolved aspects remain regarding how repetition speed evolves across different techniques and how training-induced neuromuscular adaptations are reflected in technique-specific performance outcomes. These observations indicate the need for a focused examination of repetition speed dynamics within applied training contexts and serve as a conceptual basis for further investigation.

In this context, greater attention has been directed toward technique-specific manifestations of repetition speed in junior athletes. Fundamental techniques such as Gyaku-Tsuki and Mae-Geri require repeated high-speed execution and place distinct demands on neuromuscular coordination and control. The 10–12-year age range represents a formative developmental stage in which motor patterns and technical habits are actively established. This makes it particularly relevant for targeted interventions aimed at repetition speed development. Within this framework, the systematic use of athletics-based training approaches may represent a relevant means of influencing repetition speed development in junior athletes. Such an approach allows the examination of how general neuromuscular adaptations induced by athletics-based exercises are transferred to the repetitive execution of fundamental striking techniques. The aim of this study was to comparatively analyze the development of repetition speed in Gyaku-Tsuki and Mae-Geri techniques in junior Kempo athletes aged 10–12 years following an athletics-based training intervention.

Materials and Methods

Participants

The study included a total of 24 male junior Kempo athletes aged between 10 and 12 years. Participants were allocated into two groups: an experimental group (n = 12) and a control group (n = 12). All athletes had a minimum of one year of training experience and regularly participated in sport-specific training activities related to Kempo. The selection of this age range was justified by the high level of neuromuscular plasticity characteristic of early developmental stages. This characteristic is favorable for functional adaptations induced by specific training [14, 15].

Inclusion and Exclusion Criteria

The inclusion criteria targeted male junior athletes aged 10–12 years who were registered with the Romanian Kempo Federation and had at least one year of practice experience. Participants demonstrated consistent attendance at training sessions within their respective clubs and had taken part in at least one official competition included in the federation's calendar. Participation in the study was based on voluntary involvement.

The exclusion criteria included athletes

presenting medical conditions or musculoskeletal injuries that could affect performance or safety during exertion. Athletes whose condition could limit the capacity for repetitive execution of striking techniques were also excluded. In addition, athletes involved concurrently in other studies were excluded. Those who failed to comply with the training protocol or researchers' instructions were excluded as well. The same applied to athletes using substances or treatments incompatible with sustained physical effort or repetitive execution capacity [16].

Informed consent was obtained from the parents or legal guardians of all participants. The study was conducted in accordance with the principles of the Declaration of Helsinki regarding research involving human subjects [17].

Study Design

The research was designed as a comparative study with repeated measurements conducted at two distinct time points: initial testing (T1) and final testing (T2). The interval between the two assessments corresponded to the duration of the intervention program applied to the experimental group, while the control group followed their regular training program. This design allowed for the analysis of changes in repetition speed of striking techniques and for the comparison of modifications between the two groups [18]. The structure and main characteristics of the athletics-based training intervention are presented in Table 1.

Testing Procedure

Testing was performed under standardized conditions in a controlled indoor environment with a constant temperature of 20–22 °C. All assessments were conducted at the same time of day to reduce the influence of circadian variations on neuromotor performance [19]. Athletes were instructed to avoid intense physical exertion for at least 24 hours prior to evaluation. Each participant underwent a familiarization period with the testing equipment and procedures. This was done to minimize learning effects and to ensure result stability [20].

Valid Execution Criteria

For both tests, a repetition was considered valid when the technique was executed correctly and the Wittygate sensor detected the presence of the striking limb. Detection occurred through interruption of the infrared signal at the predefined target point on the boxing bag. In the Gyaku-Tsuki test, a valid repetition required contact with the designated target area on the bag. Proper fist alignment and full extension of the striking arm were required, resulting in sensor activation. In the Mae-Geri test, validity was confirmed when the kicking foot contacted the predefined target zone on the bag. Sensor detection had to occur while maintaining the correct execution trajectory.

Executions that failed to activate the sensor, missed the target area, or were performed with evident technical errors were not counted. These errors included loss of balance, incomplete extension, or incorrect trajectory. This procedure ensured objective and standardized validation of repetitions across all participants. All testing procedures and execution validity were supervised and verified by an independent specialist affiliated with the Research Center for Human Performance, Faculty of Sciences, Physical Education and Informatics, Politehnica University of Bucharest.

Instruments and Measurements

Gyaku-Tsuki Repetition Speed (VRGT)

VRGT was assessed using the Wittygate electronic timing system (Microgate Srl, Bolzano, Italy) [21] through a 10-second maximal execution test. For both tests, the infrared sensors of the Wittygate system were positioned at approximately 50 cm

Table 1. Structure of the athletics-based training intervention

Training component	Experimental group	Control group
Study duration	6 months	6 months
Sessions per week	3	3
Session duration	30 min	30 min
Training integration	Integrated within regular Kempo training	Regular Kempo training only
Main training content	Hurdle jumps; multiple jumps; high-knee jumps; Mae-Geri executions over obstacles; medicine ball throws; elastic resistance exercises	Technical drills; combinations; kata practice; sparring
Targeted motor qualities	Repetition speed; coordination; explosive strength; neuromuscular control	Technical execution and general conditioning
Intensity	Moderate to high	Moderate
Work–rest structure	Short, repeated bouts with brief recovery intervals	According to regular practice
Progression	Gradual increase in execution speed, coordination demands, and task complexity	No structured progression

from the target surface of the boxing bag. Sensors were placed on either side of the expected impact trajectory of the striking limb to ensure consistent and accurate detection of valid executions across all participants. The test targeted the athletes' ability to rapidly and repetitively perform the specific technique while respecting established technical criteria within a limited time interval. The result was expressed as the total number of valid executions completed within 10 seconds. This value reflects movement frequency, the level of intersegmental coordination, and neuromuscular activation efficiency of the upper kinetic chain [22, 23]. The use of the Wittygate system enabled objective and precise recording of repetitions, ensuring good measurement reproducibility [24].

Mae-Geri Repetition Speed (VRMG)

VRMG was assessed using the same Wittygate electronic timing system, which allows precise recording of execution frequency within a predetermined time interval. The test consisted of repeated execution of the Mae-Geri technique for 10 seconds. Athletes were instructed to perform the maximum number of technically correct strikes. The analyzed parameter was the total number of executions completed during the testing interval. This parameter served as an indicator of rapid repetition capacity of a lower-limb technique [25].

This test evaluates execution speed, intersegmental coordination, postural stability, and neuromuscular activation efficiency specific to frontal kicking techniques. It represents a relevant indicator of technical and functional performance in Kempo [26, 27].

Statistical Analysis

Data were processed using the JASP software [28]. Preliminary calculations of differences between testing moments were performed using Microsoft Excel. Differences were calculated as absolute variation ($\Delta = T2 - T1$). This method is frequently employed in studies with repeated measurements to assess intervention-induced adaptations [29]. Results are presented as arithmetic means and standard error of the mean (SE). These indicators are recommended for describing central tendency and estimation precision in small sample sizes [30].

Data distribution was assessed using the Shapiro–Wilk test, which is considered one of the most sensitive tests for verifying normality in small samples [31]. When the normality assumption was not met, comparisons between the experimental and control groups were performed using the non-parametric Mann–Whitney U test. This test is recommended in sports science studies when distributions are asymmetric or variability is high [32]. Homogeneity of variances was verified using Levene's test. This test is employed to evaluate dispersion comparability between groups [33].

Statistical analysis was applied separately for the VRGT and VRMG repetition speed tests. Correlation relationships between variables were not investigated, as the main objective of the study focused on comparing the effects of the intervention on repetitive performance [29]. The level of statistical significance was set at $p < 0.05$, in accordance with conventions used in biomedical and sports research [30].

Results

The analysis of the results obtained in the repetition speed tests highlighted clear differences between the experimental group and the control group regarding performance changes between T1 and T2. In the case of VRGT, mean values indicate an increase in the number of executions in both groups. However, the improvement was more pronounced in the experimental group. The descriptive dynamics of Gyaku-Tsuki repetition speed between the two testing moments are presented in Table 2.

Table 2. Dynamics of Gyaku-Tsuki Repetition Speed (VRGT) between T1 and T2

Group	N	Mean T1	Mean T2	Δ (T2–T1)
Experimental	12	23.50	27.42	3.92
Control	12	20.58	23.00	2.42

N – number of participants; Mean T1 – mean number of valid executions at initial testing; Mean T2 – mean number of valid executions at final testing; Δ (T2–T1) – absolute change between final and initial testing.

According to the data presented in Table 2, the experimental group recorded a mean improvement of $\Delta = +3.92$ repetitions, compared with $\Delta = +2.42$ repetitions in the control group. Although the descriptive difference suggests a favorable effect of the intervention, statistical analysis did not reveal a significant difference between the distributions of the two groups ($p > 0.05$). Such results are frequently observed in studies with small sample sizes and high individual variability [32, 34]. The results of the inferential statistical analysis for VRGT are summarized in Table 3.

Table 3. Inferential statistical analysis of VRGT

U	(p)	Mean rank - EG	Mean rank - CG	Sum of ranks - EG	Sum of ranks - CG	Levene's test (p)
90.0	0.31	14.0	11.0	168.0	132.00	0.25

U – Mann–Whitney U statistic; p – significance level; Mean rank – average rank for each group; Sum of ranks – total rank sum for each group; EG – experimental group; CG – control group; Levene's test (p) – probability value for the homogeneity of variances.

The statistical variability indicators indicate greater dispersion of values in the control group, whereas the experimental group exhibits more homogeneous results. This pattern suggests superior stability of repeated executions in the experimental group and is consistent with findings reported in the specialized literature [35].

The evolution of mean VRGT values across testing moments for both groups is illustrated in Figure 1. The graphical representation confirms a more consistent progression of performance within the experimental group.

With regard to VRMG, the differences between groups were considerably more pronounced. The descriptive dynamics of Mae-Geri repetition speed between T1 and T2 are presented in Table 4.

Table 4. Dynamics of Mae-Geri Repetition Speed (VRMG) between T1 and T2

Group	N	Mean T1	Mean T2	Δ (T2–T1)
Experimental	12	14.58	17.58	3.00
Control	12	19.25	13.58	-5.67

The experimental group recorded a clear increase in repetition speed between T1 and T2 (Δ = +3.00), indicating an improvement in the capacity for repeated execution of the technique. In contrast, the control group exhibited a marked decrease in performance (Δ = −5.67). This decline reflects a reduced ability to maintain execution rhythm, possibly associated with neuromuscular fatigue and the absence of specific training stimuli [36]. The results of the inferential statistical analysis for VRMG are presented in Table 5.

Table 5. Inferential statistical analysis of VRMG

U	(p)	Mean rank - EG	Mean rank - CG	Sum of ranks - EG	Sum of ranks - CG	Levene's test (p)
144.0	< .001	18.5	6.5	222.0	78.0	0.12

The Mann–Whitney U test confirmed the presence of a statistically significant difference between the two groups in the case of VRMG ($p < 0.001$). The rank distribution indicates a clear superiority of the experimental group. The reduced variability of values within this group suggests a more stable execution pattern and more efficient neuromuscular control, which is in line with previous findings in combat sports research [37].

Overall, the results indicate that the applied intervention had a moderate impact on VRGT and a significant effect on VRMG. This suggests that neuromotor adaptations induced by the training program are more strongly reflected in techniques involving larger body segments and higher demands for intersegmental coordination and postural stability [35, 36]. The graphical representation of mean values illustrates the distinct evolution of Mae-Geri repetition speed between T1 and T2 for the two groups (Figure 2).

Discussion

The aim of this study was to analyze the evolution of repetition speed in the VRGT and VRMG tests in junior Kempo athletes and to highlight the effects of an intervention based on athletics-specific exercises oriented toward the development of repeated execution speed, in comparison with a control group. The obtained results indicate visible improvements in neuromotor performance within the experimental group. These findings confirm the effectiveness of the applied training program and support the importance of speed- and coordination-specific exercises in the preparation of young athletes [29, 30]. To the authors' knowledge, this study represents the first comparative investigation of repetition speed adaptations in Gyaku-Tsuki and Mae-Geri techniques in junior Kempo athletes following a structured athletics-based training intervention. The novelty of the

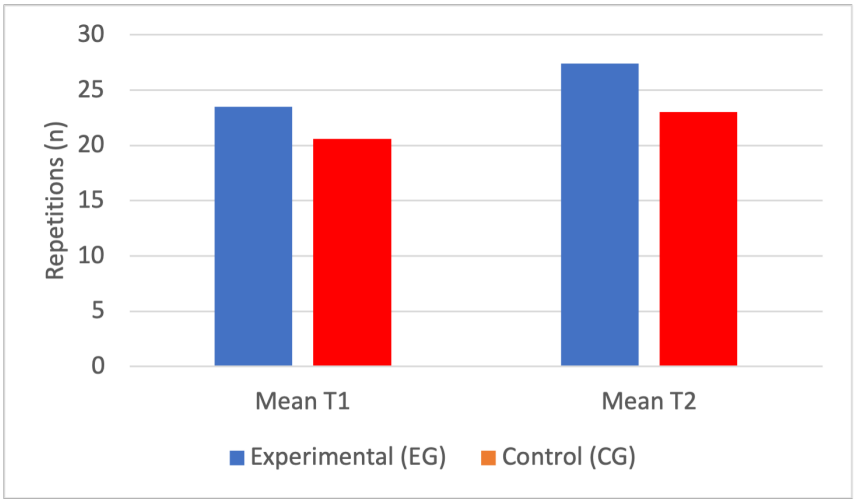

Figure 1. Mean values of Gyaku-Tsuki repetition speed (VRGT) for the experimental and control groups at T1 and T2

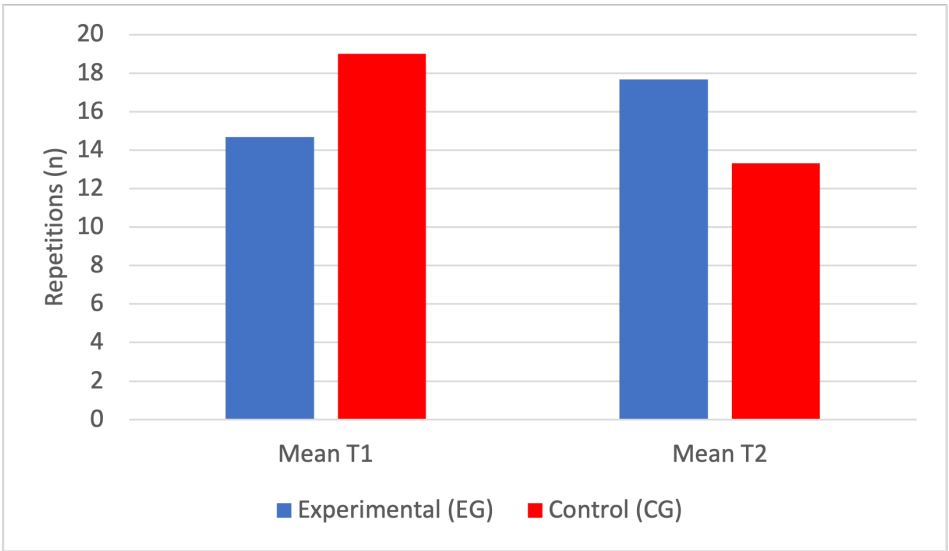

Figure 2. Mean values of Mae-Geri repetition speed (VRMG) for the experimental and control groups at T1 and T2

present research lies in the systematic integration of athletics-derived drills specifically designed to enhance repeated execution speed of fundamental Kempo techniques, rather than general physical conditioning. Furthermore, focusing on the 10–12-year age category addresses a critical developmental period in which neuromotor patterns and technical habits are established. This provides valuable insights for long-term athlete development. From a practical perspective, the findings offer coaches evidence-based guidance for optimizing repetition speed training in youth Kempo athletes through transferable athletic exercises.

In the case of VRGT, the analysis of results revealed an increase in the number of executions performed within the 10-second interval in both the experimental and control groups. However, the improvement was more pronounced among athletes who benefited from the intervention. This evolution suggests an enhanced capacity to maintain execution rhythm and movement frequency specific to the Gyaku-Tsuki technique. Although the differences between groups did not reach the threshold of statistical significance, the observed descriptive trend is consistent with research. Previous studies indicate that adaptations in upper-limb repetition speed may require longer intervention periods or higher volumes of specific stimulation in order to become statistically evident [31, 32].

An important role in these adaptations is played by the systematic inclusion of athletics-specific exercises in the training structure of the experimental group. Accelerated running drills, short-distance sprints, and coordination exercises contribute to the development of movement frequency and to the optimization of neuromuscular control. These exercises facilitate rapid and coordinated activation of motor units involved in the repetitive execution of upper-limb striking techniques [31]. Such mechanisms are essential for maintaining a consistent execution rhythm in repetition speed tests.

With regard to VRMG, the results revealed more pronounced differences between the two groups. The experimental group recorded a significant increase in the number of repetitions between T1 and T2. In contrast, the control group exhibited a clear decline in performance. This evolution indicates that the applied intervention had a major impact on the athletes' capacity to repeatedly and rapidly execute the Mae-Geri technique. This technique requires complex coordination between body segments, postural stability, and efficient control of the lower-limb neuromuscular chain [33, 34].

The athletics-based elements introduced into training contributed substantially to the optimization of VRMG. Jumping exercises, running drills with rhythm variations, and basic plyometric exercises promote the development of explosive strength and muscle contraction speed. These qualities are critical factors for the repeated execution of kicking techniques. Such adaptations allow the maintenance of a high performance level throughout the test duration. They also reduce rhythm decrements associated with neuromuscular fatigue, as reported in other research on combat sports [36].

Another relevant aspect highlighted by the obtained data is the variability of Δ values. This variability was more pronounced in the experimental group, particularly for VRMG. It reflects individual differences in response to the intervention and is characteristic of training programs oriented toward speed and repetitive executions. In such programs, adaptations are influenced by initial training level, coordination, and biological maturation [30, 37].

From a practical perspective, the study results emphasize the importance of integrating athletics-

based exercises into the preparation of junior Kempo athletes. The use of running drills, sprints, coordination exercises, and jumps contributes to the development of fundamental neuromotor capacities. It also facilitates their transfer to the repeated execution of combat-specific techniques. Performance monitoring through standardized repetition speed tests conducted using the Wittygate system provides coaches with objective information for adjusting and individualizing training programs [29, 33].

In conclusion, the obtained results demonstrate that the introduction of athletics-specific elements into the training structure had a positive impact on VRGT and a significant effect on VRMG in junior athletes. These findings support the necessity of an integrative approach in combat sports preparation. In this approach, the development of repeated execution speed through athletic means is harmonized with the refinement of Kempo-specific techniques. This contributes to increased training efficiency and sports performance [34, 38].

Recommendations

Based on the results obtained in the present study, the following practical recommendations can be formulated for coaches and instructors involved in the preparation of junior Kempo athletes.

1. Clear structuring of the training process. Training sessions should be organized in a logical and progressive manner, with well-defined objectives aimed at developing repeated execution speed. Clear explanations and visual demonstrations of the Gyaku-Tsuki and Mae-Geri techniques contribute to a correct understanding of motor demands. They also support the optimization of execution rhythm during exercises.
2. Individualized approach to training loads. An initial assessment of repetition speed level is recommended for each athlete, both in the VRGT and VRMG tests. This allows exercise volume, intensity, and density to be adapted to individual capacities. The interindividual differences observed in Δ values justify the need for personalized adjustment of training tasks.
3. Integration of athletics-based elements into training. The systematic inclusion of athletics-specific exercises, such as short-distance speed runs, acceleration drills, bilateral and unilateral jumps, and speed–strength exercises for the lower limbs, contributes to improving repeated execution speed. These training means support the development of movement frequency, rapid motor unit activation, and maintenance of execution rhythm in the VRGT and VRMG tests.
4. Development of coordination and execution stability. Training sessions should include exercises that require rapid and repeated executions under conditions of technical control. Emphasis should be placed on segmental synchronization and maintenance of movement quality. These exercises contribute to increased performance stability and to the reduction of uncontrolled variations in execution rhythm.
5. Systematic monitoring of progress. Periodic use of standardized repetition speed tests for Gyaku-Tsuki and Mae-Geri is recommended. Assessments should be conducted at different time points (T1 and T2), with calculation of Δ differences (T2–T1). Recording results in individual performance sheets allows monitoring of each athlete's progression and continuous adjustment of the training program.
6. Interdisciplinary approach to training. Collaboration between coaches, instructors, and physical training specialists is recommended for the development of coherent training programs. Such programs should integrate repeated execution speed development, coordination, and explosive strength in accordance with the technical demands specific to Kempo.
7. Use of modern assessment technologies. The integration of electronic measurement systems such as Wittygate increases the objectivity of repetition speed evaluation and provides precise feedback on performance. These technologies can contribute to increased athlete motivation and to improved control of the training process.

A limitation of the present study is the relatively small sample size (n = 12 per group), which may have reduced statistical power, particularly for VRGT outcomes. Therefore, the findings should be interpreted as exploratory.

Conclusions

The comparative analysis of the results obtained in the VRGT and VRMG repetition speed tests highlights neuromuscular adaptations among the junior athletes included in the experimental group. The increase in Δ values for both indicators confirms an improvement in the capacity for rapid and repeated execution of sport-specific techniques as a direct effect of the applied intervention.

In contrast, the control group showed limited progress. In the case of VRMG, a decrease in performance was observed, suggesting the absence of relevant functional adaptations in the lack of a targeted training program. These differences support the notion that the development of repetition speed depends on specific stimuli aimed at neuromuscular control, intersegmental coordination, and technical execution efficiency.

The integration of athletics-based exercises into the structure of Kempo-specific training proved to be an effective strategy for optimizing repetition speed in both analyzed techniques. Speed runs, acceleration drills, jumps, and strength–speed

exercises contributed to improving the capacity for rapid motor unit activation. They also supported the maintenance of a high execution rhythm throughout the 10-second test duration.

The differences observed between the two testing moments indicate that the intervention had a more pronounced impact on VRMG. This technique involves larger body segments and requires a higher level of intersegmental coordination and neuromuscular control. This finding underscores the need for a differentiated approach to striking techniques in the training of junior athletes, depending on the specific biomechanical and neuromotor demands of each action.

Overall, the study results provide scientific support for the systematic inclusion of athletics-based elements in the training of junior Kempo athletes. This approach represents an effective means of developing repetition speed and sport-specific technical performance. These conclusions may contribute to the optimization of training programs and to increasing the efficiency of striking technique execution in combat sports.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

Use of Artificial Intelligence Tools

During the preparation of this manuscript, the authors used the artificial intelligence based tool ChatGPT (OpenAI) to obtain linguistic suggestions, synonyms, reformulations, translations, and guidance toward publicly available web resources. Artificial intelligence tools were not used for data analysis, statistical processing, interpretation of results, or the generation of original scientific content. All suggestions were critically reviewed and adapted by the authors. The authors assume full responsibility for the final content of the manuscript.

References

1. Sánchez-Medina L, González-Badillo JJ. Velocity Loss as an Indicator of Neuromuscular Fatigue during Resistance Training. *Medicine & Science in Sports & Exercise*, 2011;43(9): 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880
2. Cormie P, McGuigan MR, Newton RU. Developing Maximal Neuromuscular Power: Part 1 – Biological Basis of Maximal Power Production. *Sports Medicine*, 2011;41(1): 17–38. https://doi.org/10.2165/11537690-000000000-00000
3. Chaabène H, Hachana Y, Franchini E, Mkaouer B, Chamari K. Physical and Physiological Profile of Elite Karate Athletes: *Sports Medicine*, 2012;42(10): 829–843. https://doi.org/10.2165/11633050-000000000-00000
4. Cid-Calfucura I, Herrera-Valenzuela T, Franchini E, Falco C, Alvial-Moscoso J, Pardo-Tamayo C, et al. Effects of Strength Training on Physical Fitness of Olympic Combat Sports Athletes: A Systematic Review. *International Journal of Environmental Research and Public Health*, 2023;20(4): 3516. https://doi.org/10.3390/ijerph20043516
5. Franchini E, Artioli GG, Brito CJ. Judo combat: time-motion analysis and physiology. *International Journal of Performance Analysis in Sport*, 2013;13(3): 624–641. https://doi.org/10.1080/24748668.2013.11868676
6. Cormie P, McBride JM, McCaulley GO. Power-Time, Force-Time, and Velocity-Time Curve Analysis of the Countermovement Jump: Impact of Training. *Journal of Strength and Conditioning Research*, 2009;23(1): 177–186. https://doi.org/10.1519/JSC.0b013e3181889324
7. Lloyd RS, Oliver JL, Faigenbaum AD, Howard R, De Ste Croix MBA, Williams CA, et al. Long-Term Athletic Development- Part 1: A Pathway for All Youth. *Journal of Strength and Conditioning Research*, 2015;29(5): 1439–1450. https://doi.org/10.1519/JSC.0000000000000756
8. Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. *British Journal of Sports Medicine*, 2010;44(1): 56–63. https://doi.org/10.1136/bjsm.2009.068098
9. Bishop C, Turner A, Jarvis P, Chavda S, Read P. Considerations for Selecting Field-Based Strength and Power Fitness Tests to Measure Asymmetries. *Journal of Strength and Conditioning Research*, 2017;31(9): 2635–2644. https://doi.org/10.1519/JSC.0000000000002023
10. Kadir S, Haryanto AI. Development of the Gyaku Tsuki and Mawashi Geri Speed Test. *COMPETITOR: Jurnal Pendidikan Kepelatihan Olahraga*, 2021;13(2): 130. https://doi.org/10.26858/cjpko.v13i2.19059
11. Mocioaca D, Dragomir M. The Importance of the Speed Execution in the Technical Procedures Specific to the Style Ashihara Karate. *Bulletin of the Transilvania University of Braşov. Series IX: Sciences of Human Kinetics*, 2023; 63–70. https://doi.org/10.31926/but.shk.2023.16.65.2.8
12. Dos Santos MH, Yusmawaty Y, Samsudin S, Dos Santos HA, Kamaruddin I, Hasnah H, et al. Effectiveness Of Developing A Model Of Punches And Kick Speed Excercise For Karate Martial Arts. *Balneo and PRM*

Research Journal, 2025;No. 4, December 2025(Vol 16). https://doi.org/10.12680/balneo.2025.916
13. Chen B, Deng L, Liu Y, Deng X, Yuan X. The Effect of Integrative Neuromuscular Training on Enhancing Athletic Performance: A Systematic Review and Meta-Analysis. *Life*, 2025;15(8): 1183. https://doi.org/10.3390/life15081183
14. Malina RM, Bouchard C, Bar-Or O. *Growth, Maturation, and Physical Activity*.. 2nd edn Human Kinetics; 2004. https://doi.org/10.5040/9781492596837
15. Lloyd RS, Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength & Conditioning Journal*, 2012;34(3): 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea
16. Faigenbaum AD, Kraemer WJ, Blimkie CJR, Jeffreys I, Micheli LJ, Nitka M, et al. Youth Resistance Training: Updated Position Statement Paper From the National Strength and Conditioning Association. *Journal of Strength and Conditioning Research*, 2009;23(Supplement 5): S60–S79. https://doi.org/10.1519/JSC.0b013e31819df407
17. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. *JAMA*, 2013;310(20): 2191. https://doi.org/10.1001/jama.2013.281053
18. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise*, 2009;41(1): 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278
19. Atkinson G, Reilly T. Circadian Variation in Sports Performance: *Sports Medicine*, 1996;21(4): 292–312. https://doi.org/10.2165/00007256-199621040-00005
20. Atkinson G, Nevill AM. Statistical Methods For Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine: *Sports Medicine*, 1998;26(4): 217–238. https://doi.org/10.2165/00007256-199826040-00002
21. Microgate Srl. *Wittygate timing system: technical specifications and applications*. Bolzano (Italy) [Internet]. 2024 [updated 2025 Jun; cited 2025 Sep 28]. Available from: https://training.microgate.it/en/products/witty/wittygate
22. Chaabene H, Negra Y, Bouguezzi R, Capranica L, Franchini E, Prieske O, et al. Tests for the Assessment of Sport-Specific Performance in Olympic Combat Sports: A Systematic Review With Practical Recommendations. *Frontiers in Physiology*, 2018;9: 386. https://doi.org/10.3389/fphys.2018.00386
23. Sbriccoli P, Camomilla V, Di Mario A, Quinzi F, Figura F, Felici F. Neuromuscular control adaptations in elite athletes: the case of top level karateka. *European Journal of Applied Physiology*, 2010;108(6): 1269–1280. https://doi.org/10.1007/s00421-009-1338-5
24. Impellizzeri FM, Rampinini E, Marcora SM. Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, 2005;23(6): 583–592. https://doi.org/10.1080/02640410400021278
25. Lenetsky S, Uthoff A, Coyne J, Cronin J. A Review of Striking Force in Full-Contact Combat Sport Athletes: Methods of Assessment. *Strength & Conditioning Journal*, 2022;44(1): 71–83. https://doi.org/10.1519/SSC.0000000000000643
26. McGill S. Core Training: Evidence Translating to Better Performance and Injury Prevention. *Strength & Conditioning Journal*, 2010;32(3): 33–46. https://doi.org/10.1519/SSC.0b013e3181df4521
27. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, 2016;116(6): 1091–1116. https://doi.org/10.1007/s00421-016-3346-6
28. JASP Team. *JASP* (Version 0.95.3) [computer software]. [Internet]. Amsterdam; 2025. [updated 2025 Jun; cited 2025 Sep 28]. Available from: https://jasp-stats.org
29. Hopkins WG. Measures of Reliability in Sports Medicine and Science: *Sports Medicine*, 2000;30(1): 1–15. https://doi.org/10.2165/00007256-200030010-00001
30. Portney LG, Watkins MP. *Foundations of clinical research: applications to practice*. 3rd ed. Upper Saddle River (NJ): Pearson; 2009.
31. Razali N, Yap BW. Power comparisons of some selected normality tests. In: *Proceedings of the Regional Conference on Statistical Sciences (RCSS'10)*; 2010 Jun 12–13; Shah Alam, Malaysia. P. 126–138.
32. Field A. *Discovering statistics using IBM SPSS statistics*. 5th ed. London: Sage; 2018.
33. Levene H. Robust tests for equality of variances. In: Olkin I, editor. *Contributions to probability and statistics*. Stanford: Stanford University Press; 1960. P. 278–292.
34. Button KS, Ioannidis JPA, Mokrysz C, Nosek BA, Flint J, Robinson ESJ, et al. Power failure: why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience*, 2013;14(5): 365–376. https://doi.org/10.1038/nrn3475
35. Enoka RM, Farina D. Force Steadiness: From Motor Units to Voluntary Actions. *Physiology*, 2021;36(2): 114–130. https://doi.org/10.1152/physiol.00027.2020
36. Allen DG, Lamb GD, Westerblad H. Skeletal Muscle Fatigue: Cellular Mechanisms. *Physiological Reviews*, 2008;88(1): 287–332. https://doi.org/10.1152/physrev.00015.2007
37. Lloyd RS, Oliver JL, Faigenbaum AD, Myer GD, De Ste Croix MBA. Chronological Age vs. Biological Maturation: Implications for Exercise Programming in Youth. *Journal of Strength and Conditioning Research*, 2014;28(5): 1454–1464. https://doi.org/10.1519/JSC.0000000000000391
38. Mihailescu L, Chiriac PB, Mihailescu LE, Manolachi V, Potop V. Determining the capacity for effort and recovery of the elite soccer players specialized in different playing positions. *PeerJ*, 2023;11: e15477. https://doi.org/10.7717/peerj.15477

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ORIGINAL ARTICLE

The effect of core stability training on improving balance moderated by strength in early age karate students

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Abstract

Background and Study Aim: Core stability training is commonly used in youth martial arts practice to support postural control. Different training approaches and individual strength levels may influence balance outcomes in young karate athletes. Despite the application of various training methods, their relative effectiveness in improving balance remains a matter of practical interest. The purpose of this study was to investigate the effect of core stability training on balance improvement in young karateka.

Material and Methods: This 2×2 factorial experiment included 40 male karateka (aged 6–8 years) selected through purposive sampling and grouped using matched-subject ordinal pairing. The research instruments consisted of the plank test and the star excursion balance test. Data analysis techniques were Two-Way ANOVA, Tukey's post hoc test ($p < 0.05$), and effect size calculation (partial eta squared) using SPSS version 23.

Results: There was a significant effect of the training method (core stability vs. control) ($p = 0.000$; $\eta p^2 = 0.707$). There was a significant effect of core muscle strength (high vs. low) ($p = 0.000$; $\eta p^2 = 0.730$). There was a significant interaction between the training method (core stability vs. control) and core muscle strength (high vs. low) ($p = 0.009$; $\eta p^2 = 0.174$).

Conclusions: The effectiveness of training in improving balance is not determined only by a single training method but is also strongly moderated by core muscle strength. Although both the core stability training method and core muscle strength factors have a moderate-to-high effect, the presence of a substantial interaction indicates that each karateka's response is different. Identifying core muscle strength in young karateka is critical for achieving optimal balance.

Keywords: core stability, core muscle strength, balance, moderating effect, early age karateka.

Introduction

Maintaining postural stability is a fundamental requirement for effective execution of technical actions in youth karate practice. During early training stages, balance development determines the ability to control body position during kicks, turns, and transitions between stances. This ability depends not only on coordination but also on neuromuscular control and trunk stabilization capacity. Variability in individual physical characteristics, particularly strength-related factors, can substantially influence how young athletes maintain stability during movement.

Karate demands both proper technique and physical fitness. Every punch and kick requires physical components such as speed, strength, and balance [1]. Karate students aged 6–8 years enter a crucial period of neuromuscular adaptation. Training programs are intended to integrate physical training to reduce injury risk and ensure a more stable transition to senior levels [2, 3]. One important physical aspect is balance. When karateka execute a punch followed by a kick with a rapid shift from stance to stance, balance stabilizes the supporting leg muscles. Instability in dynamic situations frequently leads to a loss of body control, reducing movement effectiveness and increasing the risk of injury.

The core stability training model is a cornerstone for developing karateka balance. In addition to technical training, karateka should integrate core stability training for safety during training and competition [4]. This training focuses on

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strengthening the muscles surrounding the trunk, particularly the transversus abdominis, to improve stability [5, 6]. Core stability exercise builds a foundation for producing more efficient power in the upper and lower extremities while preserving abdominal muscle stability [7, 8]. Several studies have found a positive effect of core stability training on athlete performance in sports such as soccer, futsal, and volleyball [9, 10, 11].

Despite the extensive documentation of core stability training effectiveness, its use in karate remains debatable. Compared with karate technique training alone, core stability training enhances kicking performance and core muscle strength, according to Kamal et al. [12] and Del et al. [13]. Rahimi reported that integrating core training did not outperform karate technique training alone [14]. This inconsistency raises questions regarding factors that affect training effectiveness.

The key factor may be the synergy of stability and strength. In the context of kata movements, athletes perform complex transitions from dynamic to static actions, such as jumps and spins, which require appropriate muscle strength to maintain balance. Rahma reported that core muscle strength influences balance in martial arts [15]. Zhang et al. demonstrated that core stability training improves kicking, punching, and core muscle strength performance in taekwondo, boxing, muay thai, and karate [16]. Ebrahimi et al. showed that core stability training enhances dynamic balance, medial-posterior direction performance, and kicking performance in taekwondo [17]. Weakness in the core muscles can inhibit quadriceps and hamstring contraction [4], directly reducing technique effectiveness [18].

Several studies described above provide evidence that core muscle strength contributes to good balance. Although core muscle strength is not the only factor influencing success, Baban showed that low core muscle strength is associated with a higher risk of injury in kata and kumite athletes [19]. Empirical evidence directly linking balance level with core muscle strength in karateka remains limited. In previous research, core muscle strength was treated as a dependent variable rather than as a moderating variable that could influence balance outcomes. It remains unclear whether karateka with low core muscle strength demonstrate poorer balance. Additionally, core stability training studies still do not consider moderating variables such as training duration and level [20].

Analysis of research findings has shown that core stability training contributes to balance performance and technical effectiveness in combat sports. Researchers emphasize that the interaction between stabilization capacity and muscular strength plays an important role during complex dynamic movements typical of karate practice. At the same time, the mechanisms through which individual strength characteristics influence training outcomes remain insufficiently clarified in practical training conditions. This aspect complicates the interpretation of training effects and limits the precision of training program design for young karate athletes.

In addition, it should be noted that although these studies are relevant, they do not identify core muscle strength as a moderating influence. No research has examined core muscle strength as a moderating component influencing balance in karate, particularly at an early age.

Based on this research gap, the purpose of this study was to investigate the effect of core stability training on balance improvement in young karateka, using core muscle strength as a moderating variable. The proposed hypotheses are as follows.

1. There is a difference in the effect of the core stability training group and the conventional group on improving young karateka's balance.
2. There is a difference in the effect of high and low core muscle strength on young karateka's balance abilities.
3. There is an interaction between the core stability training group and the conventional group, as well as core muscle strength (high and low), in improving young karateka's balance.

Materials and Methods

Participants

his study used a 2×2 factorial design [21]. The 2×2 factorial approach included two independent training variables, one dependent variable, and one moderating variable [22]. The sampling technique was purposive, with the following criteria: (1) white and yellow belt levels, (2) membership in the same training club, (3) training age of one year or less to ensure the training program effect, (4) willingness to carry out the training program for six weeks, three times per week with at least 80% attendance, (5) male gender, and (6) age 6–8 years. Exclusion criteria included a history of musculoskeletal injury within the previous six months, involvement in additional strength training programs outside this trial, and withdrawal during the six-week intervention. To reduce selection bias, data were collected by a research assistant who was not involved in test administration.

Out of 47 participants, 7 did not meet the inclusion criteria because they were older than 6–8 years and had trained for more than 2 years. As a result, the study included 40 male participants with an average age of 7.2 ± 0.8 years, body mass of 27.5 ± 3.2 kg, and height of 122.4 ± 5.1 cm. To evaluate static strength, all participants underwent a plank test [23]. The scores were ranked from highest to lowest. The matched-subject ordinal pairing (MSOP)

pattern was then applied from the highest to the lowest results in the A–B–B–A order, as illustrated in Table 1 [24]. Twenty participants were assigned to conventional training and twenty to core stability training. Each group was divided into high- and low-strength subgroups: A1B1, A1B2, A2B1, and A2B2. Table 2 shows the 2×2 factorial design.

Table 1. Illustration of MSOP distribution based on the A–B–B–A pattern

Score Ranking	MSOP Pattern	Group	
1	A	Experiment	-
2	B	-	Control
3	B	-	Control
4	A	Experiment	-
5	A	Experiment	-
6	B	-	Control
7	B	-	Control
8	A	Experiment	-
9	A	Experiment	-
10	B	-	Control
11	B	-	Control
12	A	Experiment	-
13	A	Experiment	-
14	B	-	Control
15	B	-	Control
16	A	Experiment	-
17	A	Experiment	-
18	B	-	Control
19	B	-	Control
20	A	Experiment	

Note. MSOP — Matched-Subject Ordinal Pairing.

Table 2. 2x2 factorial design

Training Method (A) / Strength (B)	Conventional training (A1)	Core stability training (A2)
High strength (B1)	A1B1	A2B1
Low strength (B2)	A1B2	A2B2

Note. A1B1: Conventional training with high muscle strength; A1B2: Conventional training with low muscle strength; A2B1: Core stability training with high muscle strength; A2B2: Core stability training with low muscle strength.

Research Design

The first stage was the administration of the Star Excursion Balance Test (SEBT) to the entire group as a balance pretest. A core stability training program was then conducted for six weeks, with three training sessions per week. After the intervention was completed, a posttest was administered to determine the effectiveness of the treatment.

The training program protocols were as follows: warm-up and stretching using raise, activation, mobilization, and potentiation (RAMP) [25, 26]. The raise phase consisted of coordinated movements lifting the front, side, and back thighs, as well as arm stretches, repeated 2–3 times per movement for a total of 2 minutes. Activation and mobilization exercises included squats, lateral squats, splits, and back stretches. This phase lasted approximately 5–6 repetitions per movement for a total of 3 minutes. During the potentiation phase, participants observed and performed instructor-guided core stability movements, each held for 5 seconds for a total of 15 seconds. The next step was core stability exercises. After completing core stability training, passive stretching was performed.

The conventional (control) group performed standard karate training, which included technical exercises (kihon) but no additional core stability exercises, followed by warm-up and stretching using RAMP. The difference occurred in the potentiation phase, which consisted of technical karate movements performed 5 repetitions each for a total of 15 repetitions. The training session duration was 60–90 minutes, with a frequency of three times per week, repetitions or work time of 10–15 repetitions or 15–20 seconds, intervals of 15–20 seconds, recovery of 60–90 seconds, and progressive increases in intensity or volume every 1–2 weeks by adding repetitions or work time. The program was designed by the research team based on recommendations from karate and physical conditioning trainers. Compliance was measured by manual attendance at each training session, and the average participant attendance rate was 92%, exceeding the minimum requirement of 80%. All participants included in the final analysis met the minimum attendance criteria. The training program is described in Tables 3 and 4.

Statistical Analysis

The data were processed using SPSS version 23. The Shapiro-Wilk normality test and Levene homogeneity test were used as prerequisite tests. A two-way analysis of variance (ANOVA) and a Tukey post hoc test were used to assess the hypotheses at a significance level of 0.05 [26, 27, 28]. Effect sizes were determined using partial eta squared with standard thresholds of small (0.2), moderate (0.5), and large (0.8) [29].

Results

Table 5 shows that each group increased significantly from pretest to posttest. For example, the posttest score (98) of the A1B1 group was higher than the pretest score (92). The posttest score (92) of the A1B2 group was higher than the pretest score (86). The posttest score of the A2B1 group (105) was higher than its pretest score (94). The posttest

Table 3. Technique-focused exercise program of the control group

Week	Material	Dosage
1-2	Horse stance and punch practice a. Kiba dachi (middle stance) + zuki (punch). b. Zenkutsu dachi (side stance) + zuki (punch). c. Kokutsu dachi (back-heavy stance) + zuki (punch).	a. 10-15 reps or 15-20 seconds of work time, etc. Sets 4-5-6, etc. b. 10-15 reps or 15-20 seconds of work time, etc. Sets 4-5-6, etc. c. 10-15 reps or 15-20 seconds of work time, etc. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes
3-4	Stepping and punching exercises a. Zenkutsu dachi forward step and oi zuki (front punch). b. Zenkutsu dachi forward step and gyakuzuki (reverse punch). c. Zenkutsu dachi forward step and oi zuki + gyakuzuki.	a. Forward 5 times and backward 5 times. Sets 4-5-6, etc. b. Forward 5 times, backward 5 times. Sets 4-5-6, etc. c. Forward 5 times, backward 5 times. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes
5-6	Practice stepping in a combination of stances and punches a. Heiko dachi (shoulder-width stance) and chudan zuki (punch to the stomach), step forward in zenkutsu dachi stance at the same time as oi zuki. b. Heiko dachi (shoulder-width stance) and 2x chudan zuki punches, step forward in zenkutsu dachi stance with oi zuki and gyakuzuki. Zenkutsu dachi steps forward and strikes 3x (oi zuki, gyakuzuki, oi zuki).	a. 5 chudan punches – 5 oi zuki. Sets 4-5-6, etc. b. 5 chudan punches – 5 oi zuki – 5 gyakuzuki. Sets 4-5-6, etc. c. 2 steps for a total of 6 forward punches, 2 steps back for a total of 6 punches. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes

Table 4. Karate core stability training program

Week	Material	Dosage
1-2	Basic stability phase a. Low plank (knees on the floor) b. Bird dog (hands and feet facing opposite directions) c. Knee to elbow (modified crunch) Application: trunk stability, dynamic balance control	a. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. b. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. c. 8-10 reps, etc. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes
3-4	Strengthening phase a. Full plank (straight legs) b. Side plank c. Boat pose Application: stabilizes movement, increases hip rotation strength	a. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. b. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. c. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes
5-6	Functional stability and balance phase a. Plank with shoulder taps b. Leg raise to V-sit up c. Low plank (using stability ball) Application: maintaining posture and muscle control	a. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. b. 8-10 reps, etc. Sets 4-5-6, etc. c. Hold for 15-20 seconds, etc. Sets 4-5-6, etc. • Interval 15-20 seconds • Recovery 60 seconds • Exercise duration 60-90 minutes

Table 5. Results of descriptive analysis of pretest-posttest

Method	Strength cluster	Pretest	Posttest
Conventional training	A1B1 (high)	92 ± 2.981	98 ± 3.479
	A1B2 (low)	86.8 ± 5.147	97.20 ± 5.147
Core stability training	A2B1 (high)	94 ± 3.521	105 ± 4.001
	A2B2 (low)	75.2 ± 3.028	88.20 ± 3.479

score (88.20) of the A2B2 group was higher than the pretest score (75.2).

A normality test was conducted using the Shapiro–Wilk test. All pretest groups (A1B1, A1B2, A2B1, and A2B2) and posttest groups (A1B1, A1B2, A2B1, and A2B2) had a significance value of 0.200 (> 0.05), indicating that the data were normally distributed. Therefore, the analysis proceeded to the homogeneity test.

The homogeneity test using Levene's test produced F = 1.037 with df1 = 3 and df2 = 36 and a significance value of 0.388 (> 0.05), indicating that the data had homogeneous variance.

The analysis showed a significant difference between the two training methods (Sig = 0.000 < 0.05). The Type III Sum of Squares was 1452.0251 with df = 1, Mean Square = 1452.025, and F = 87.078. The core stability group obtained a mean score of 91.5, which was higher than the conventional group (87.5). The partial eta square effect size was 0.707, indicating a moderate effect of the training method on balance scores.

There was a significant difference between the high and low core muscle strength groups (Sig = 0.000 < 0.05). The Type III Sum of Squares was 1625.625 with df = 1, Mean Square = 1625.625, and F = 97.489. The high core muscle strength group had a mean score of 95.3, whereas the low core muscle strength group had a mean score of 83.25. The partial eta square effect size was 0.730, indicating a moderate effect of core muscle strength on balance.

A significant interaction between training method and strength cluster on balance was observed (Sig = 0.009 < 0.05). The Type III Sum of Squares was 126.025 with df = 1, Mean Square = 126.025, and F = 7.558. The partial eta square effect size was 0.174, indicating a small but statistically significant interaction.

Table 6 shows that the mean difference value marked with (*) and a significance value of 0.000 < 0.05 is interpreted as a significant interaction. Examples include groups A1B1–A1B2 (conventional method with high strength moderation – conventional method with low muscle strength moderation), A1B1–A2B1 (conventional method with high strength moderation – core stability training with high strength moderation), A1B1–A2B2 (conventional method with high strength moderation – core stability training with low strength moderation), A1B2–A1B1 (conventional training with low strength moderation – conventional method with high strength moderation), A1B2–A2B2 (conventional training with low muscle strength moderation – core stability training with low muscle strength moderation), A2B1–A1B1 (core stability training with high muscle strength moderation – conventional training with high muscle strength moderation), A2B1–A2B2 (core stability training with high muscle strength moderation – core stability training with low muscle strength moderation), A2B2–A1B1 (core stability training with low muscle strength moderation – conventional training with high muscle strength moderation), A2B2–A1B2 (core stability training with moderate low muscle strength – conventional training with moderate low muscle strength), and A2B2–A2B1 (core stability training with moderate low muscle strength – core stability training with moderate high muscle strength).

Table 6. Tukey's post hoc test results

Interaction Group		Mean Difference	Std. Error	Sig.
A1B1	A1B2	9.2000*	1.82620	.000
	A2B1	8.5000*	1.82620	.000
	A2B2	24.8000*	1.82620	.000
A1B2	A1B1	-9.2000*	1.82620	.000
	A2B1	-.7000	1.82620	.981
	A2B2	15.6000*	1.82620	.000
A2B1	A1B1	-8.5000*	1.82620	.000
	A1B2	.7000	1.82620	.981
	A2B2	16.3000*	1.82620	.000
A2B2	A1B1	-24.8000*	1.82620	.000
	A1B2	-15.6000*	1.82620	.000
	A2B1	-16.3000*	1.82620	.000

Note. * indicates a significant difference at p < 0.05.

Discussion

The purpose of this study was to determine the effectiveness of core stability in improving balance in young karateka, with core muscular strength serving as a moderating variable. The findings of the research revealed that all intervention groups had a substantial increase in balance relative to pretest levels. The two-way ANOVA test revealed that the core stability method resulted in higher balance scores ($\bar{X}$ = 91.5) compared to the control group ($\bar{X}$= 87.5), with a significant effect size (p = 0.000; ηp^2 = 0.707). This suggests that core stability training produces a significantly more effective stimulus, with a moderate effect size that tends to be high. Furthermore, core muscle strength capacity plays an important role in determining optimal karateka balance. The high core strength classification had better balancing performance ($\bar{X}$ = 95.3) than the low muscular strength group ($\bar{X}$ = 83.5), with a significant effect size (p = 0.000; ηp^2 = 0.730). This suggests that strong core muscle strength is significantly better and has a moderate effect size that tends to be high.

The study's main finding was a significant interaction between training method and core muscle strength on balance (p = 0.009; ηp^2 = 0.174). This moderating effect implies that karatekas' responses to training programs are not uniform and

are heavily influenced by individual core muscular strength. Post hoc results revealed significant differences between interaction groups, including the high muscle strength control group and the low muscle strength core stability group. Higher core muscle strength allows karateka to maintain steady motions, particularly those involving transitional movements such as attacking and defending while performing techniques. Body control is essential for young karateka to establish a solid foundation.

Training kihon (basic movements), kata (a series of movements), and kumite (combat) requires good core stability and strength. Karate biomotor components include flexibility, strength, speed, and endurance [30, 31, 32]. Balance is a crucial element incorporated into these physical components. Martial arts demand movement from a standing position and circular attacks, which necessitate maintenance of body balance [33].

The core muscles are a group of muscles surrounding the pelvis, abdomen, and spine, including the obliques, abdominis, and paraspinals [34]. These muscles maintain pelvic and spinal stability (lumbopelvic stability) [35]. This stability is important since the core muscles control the majority of upper and lower extremity motions [36]. According to research, core stability training is effective for enhancing physical fitness in martial arts [4]. Dynamic karate movements allow punching and kicking techniques to be completed with maximal power concentration (kime), while retaining balance during unstable position transitions [37, 38].

For example, in kumite matches, balance is critical when punching and kicking, walking toward an opponent, and returning to the starting position. In kata matches, each movement is associated with a jump, resulting in a balanced horse stance. The use of this training becomes a pedagogical principle: a trainer must grasp a karate practitioner's skill level. Training must be founded on individualistic, specialized, and pedagogical principles [26, 31]. This is consistent with earlier research, which shows that adopting a training program necessitates basic training concepts including progressive loading, regularity, and individuality [39]. Early childhood karate training programs facilitate the pedagogical premise of exploring talent development, highlighting the importance of improving personal and social skills [40].

Similarly, the concept of long-term development throughout the 6–8-year period enters the active start and fundamental stages, and training focuses not only on technique but also on physical capacities as a foundation for optimizing technical training [41, 42]. Another study found that long-term athlete development during the pre-pubertal phase (ages 6–8) demonstrates high nervous system plasticity, and training should focus on building motor control and coordination through neuromuscular mechanisms rather than only mechanical loading [43]. Neuromuscular training should start as soon as possible to enhance movement biomechanics and reduce the risk of injury [44].

Karate athletes with low core strength should focus on stabilizing exercises such as low planks and bird dogs before attempting complex kicking techniques to ensure a safe training foundation. Karate athletes with high core strength and advanced belt levels should focus on dynamic stability training. Identifying good core muscle strength is required for karate athletes to quickly shift into horse stances while simultaneously performing punch and kick combinations, as well as turning or jumping.

These findings not only offer theoretical guidance on the relationship between core strength and balance, but they also create a scientific consensus that has not previously received special attention. Furthermore, this serves as a pedagogical reorientation for the development of karate athletes aged 6–8 years, a sensitive period for neuromuscular adaptation that is often less thoroughly explored among younger karate athletes compared to the broader demographic of adolescent and senior karate athletes.

Limitations of the Study

Research limitations include the fact that participants were only young karateka with white and yellow belt levels, so these findings may not be generalizable to karateka of older age and higher belt levels, experience, and training levels. Additionally, the sample was limited to men, so the results may not be fully applicable to female karateka. The intervention period was rather brief, which may not fully reflect long-term neuromuscular changes and may only reflect acute performance, implying that permanent adaptations require longer intervention efforts. Plank tests for core muscle strength focus on isometric or static muscle contractions, which have limitations given the dynamic nature of karate.

Future Research Directions

To ensure generalizability across both genders, future studies should increase the sample size to include karateka of higher ages and belt levels, as well as female karateka. The duration of the intervention should be increased to account for more persistent neuromuscular changes rather than merely acute performance benefits. The use of test instruments for the moderating variable of core muscular strength with the plank should be replaced with dynamic tests in the future, as the dependent variable is balance, which is dynamic in character, especially given that karate movements involve motion. Other moderating variables, such as agility, speed, and coordination, should also be investigated, as these are significant aspects of karate.

Conclusions

Based on the findings and discussion, it was determined that the group that received core stability training demonstrated superior balance compared to the conventional group. The moderating variable of high muscle strength had a greater effect than low muscle strength. In addition, there was a substantial interaction between the training method (core stability and conventional) and the level of core strength (high and low) on balance. This provides theoretical support for the claim that core strength is the primary mechanism for developing dynamic balance in young karateka. Implications: Provide concrete recommendations for trainers regarding core stability as a training element for developing dynamic balance in karateka. This program is useful for mitigating the risk of injury in dynamic and difficult karate techniques, as well as for preparing for strength training in the sensitive phase of neuromuscular adaptation.

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Conflict of Interest

All authors declare no conflict of interest.

References

1. Yudhistira D, Tomoliyus T. Content Validity of Agility Test in Karate Kumite Category. *International Journal of Human Movement and Sports Sciences*, 2020;8(5): 211–216. https://doi.org/10.13189/saj.2020.080508
2. Yudhistira D, Suherman WS, Wiratama A, Wijaya UK, Paryadi P, Faruk M, et al. Content Validity of the HIIT Training Program in Special Preparations to Improve the Dominant Biomotor Components of Kumite Athletes. *International Journal of Human Movement and Sports Sciences*, 2021;9(5): 1051–1057. https://doi.org/10.13189/saj.2021.090527
3. Lloyd RS, Oliver JL, [eds]. *Strength and Conditioning for Young Athletes: Science and Application*.. 2nd edn Second Edition. | New York: Routledge, 2019. | Previous edition: 2014.: Routledge; 2019. https://doi.org/10.4324/9781351115346
4. Li J, Du X. Core training in martial arts athletes. *Revista Brasileira de Medicina do Esporte*, 2023;29:e2022_0376. https://doi.org/10.1590/1517-8692202329012022_0376
5. Rosalina R, Wiriawan O, Mintarto E. Pengaruh latihan core stability plank dan core stability superman terhadap kekuatan otot perut dan keseimbangan [The effect of core stability plank and core stability superman exercises on abdominal muscle strength and balance]. *Jurnal Program Studi Pendidikan Jasmani dan Kesehatan,* 2019;7(2):49-54.
6. Ahmed S, Saraswat A, Esht V. Correlation of core stability with balance, agility and upper limb power in badminton players: a cross-sectional study. *Sport Sciences for Health*, 2022;18(1): 165–169. https://doi.org/10.1007/s11332-021-00789-w
7. Wirth K, Hartmann H, Mickel C, Szilvas E, Keiner M, Sander A. Core Stability in Athletes: A Critical Analysis of Current Guidelines. *Sports Medicine*, 2017;47(3): 401–414. https://doi.org/10.1007/s40279-016-0597-7
8. Dello Iacono A, Padulo J, Ayalon M. Core stability training on lower limb balance strength. *Journal of Sports Sciences*, 2016;34(7): 671–678. https://doi.org/10.1080/02640414.2015.1068437
9. Sofuoğlu C, Güçhan Topçu Z, Bayrakcı Tunay V. The effect of core stability training on ball-kicking velocity, sprint speed, and agility in adolescent male football players. Mohsenifar H (ed.) *PLOS ONE*, 2024;19(6): e0305245. https://doi.org/10.1371/journal.pone.0305245
10. Busara C, Chentanez T, Ointong T. The effects of the 11+ on agility performance in adolescent futsal players. *Journal of Sports Science and Technology*, 2018;18(1):1-8.
11. Sadeghi H, Shariat A, Asadmanesh E, Mosavat M. The effects of core stability exercise on the dynamic balance of volleyball players. *International Journal of Applied Exercise Physiology,* 2013;2(2):1–10.
12. Kamal O. Effects of core strength training on karate spinning wheel kick and certain physical variables for young females. *Science, Movement and Health*, 2015;15(Suppl 2):504–509.
13. Fei Z. Influences of strength training on performance in martial arts athletes. *Revista Brasileira de Medicina do Esporte*, 2023;29: e2023_0064. https://doi.org/10.1590/1517-8692202329012023_0064
14. Rahimi M, Samadi H, Nikzade Abbasi Z, Rahnama A. Effect of Core Stability Trainings on Functional Movement Screening Scores and Trunk Muscle Endurance in Female Kyokushin Karate Athletes. *Journal of Clinical Research in Paramedical Sciences*, 2023;12(2). https://doi.org/10.5812/jcrps-137919
15. Khotijah S, Sudiana IK, Sudarmada IN. Pengaruh Pelatihan Core Stability terhadap Keseimbangan dan Kekuatan Otot Perut Atlet Putra Ekstrakurikuler Pencak Silat [The Effect of Core Stability Training on the Balance and Abdominal Muscle Strength of Male Pencak Silat Extracurricular Athletes]. *Jurnal Ilmu Keolahragaan Undiksha*, 2023;11(3): 320–327. (In Indonesian). https://doi.org/10.23887/jiku.v11i3.65939
16. Zhang S, Huang W, Soh KG, Luo S, Li L, Wang X. Effects of core strength training on the technical skill performance of striking combat sport players: a systematic review. *PeerJ*, 2025;13: e19615. https://doi.org/10.7717/peerj.19615
17. Ebrahimi E, Mozafari S. The Effect of Six Weeks of Core Stability Training on Balance and Performance Improvement Among Male Taekwondo Athletes. *Journal of Sport Biomechanics*, 2024;10(2): 160–173. https://doi.org/10.61186/JSportBiomech.10.2.160
18. Ariansyah A, Insanistyo B, Sugiyanto S. Hubungan

keseimbangan dan power otot tungkai terhadap kemampuan tendangan dolly chagi pada atlet ukm (unit kegiatan mahasiswa) taekwondo universitas bengkulu [The relationship between balance and leg muscle power and the dolly chagi kicking ability of taekwondo athletes from the University of Bengkulu (UKM)]. *Kinestetik*, 2017;1(2). (In Indonesian). https://doi.org/10.33369/jk.v1i2.3474
19. Baban K, Farhangian M, Mohamadi S, Mohamadi F. The relationship between the amounts of core stability and lower extremity injuries in male karate-ka elites. *International Journal of Sport Studies,* 2015;5(6):721–725.
20. Yu T, Xu Y, Zhang Z, Sun Y, Zhong J, Ding C. The impact of core training on overall athletic performance in different sports: a comprehensive meta-analysis. *BMC Sports Science, Medicine and Rehabilitation*, 2025;17(1): 112. https://doi.org/10.1186/s13102-025-01159-6
21. Yudanto Y, Yudhistira D, Antoni MS, Septian M. The Effect of the Training Model and Balance on Students' Sepak Sila Skills on Sepak Takraw Extracurricular in First Middle School. *Physical Education Theory and Methodology*, 2022;22(4): 485–492. https://doi.org/10.17309/tmfv.2022.4.05
22. Sulistiyono S, Akhiruyanto A, Primasoni N, Arjuna F, Santoso N, Yudhistira D. The Effect of 10 Weeks Game Experience Learning (Gel) Based Training on Teamwork, Respect Attitude, Skill and Physical Ability in Young Football Players. *Physical Education Theory and Methodology*, 2021;21(2): 173–179. https://doi.org/10.17309/tmfv.2021.2.11
23. Wiriawan O. *Panduan pelaksanaan tes dan pengukuran olahragawan* [Guide to implementing tests and measurements for athletes]. Yogyakarta: Thema Publishing; 2017. (In Indonesian).
24. Hadi H, Yudhistira D, Romadhoni S, Kurnianto H. Analysis of Agility, Strength and Power Differences in Basketball Players in Relation to Age. *International Journal of Human Movement and Sports Sciences*, 2022;10(4): 748–753. https://doi.org/10.13189/saj.2022.100415
25. Jeffreys I. *The Warm-Up: Maximize Performance and Improve Long-Term Athletic Development*.. 1st edn Human Kinetics; 2019. https://doi.org/10.5040/9781718214170
26. Hidayah T, Akhiruyanto A, Yudhistira D, Kurnianto H. The Effects of LTAD-Based Programming on Fundamental Skills and Physical Abilities of Basketball Players Aged 11-12 Years. *Physical Education Theory and Methodology*, 2023;23(6): 909–917. https://doi.org/10.17309/tmfv.2023.6.13
27. Hidayah T, Akhiruyanto A, Haryono S, Yudhistira D. Linear and nonlinear programming: effects on the physical abilities of young basketball players. *Pedagogy of Physical Culture and Sports*, 2024;28(4): 274–282. https://doi.org/10.15561/26649837.2024.0404
28. Yudanto Y, Suherman WS, Nugroho S, Guntur G, Yudhistira D. The Effect of Games Experience Learning Model and Fundamental Movement Skills on Improving Soccer Playing Skills in Youth Soccer Players. *International Journal of Human Movement and Sports Sciences*, 2022;10(4): 815–822. https://doi.org/10.13189/saj.2022.100422
29. Intani AD, Sukoco P, Sumaryanti S, Abidin D, Prayogo G, Özman C, et al. Integrating music–movement pedagogy into inclusive physical education for children with intellectual disabilities. Pedagogy of Physical Culture and Sports, 2025;29(4): 369–378. https://doi.org/10.15561/26649837.2025.0414
30. Yudhistira D, Kurnianto H, Candra A, Ulinnuha R, Wicaksono A. Tapering in the Sport of Karate: Narrative Review. In: *Proceedings of the 6th International Seminar on Public Health and Education, ISPHE 2022, 29 June 2022, Semarang, Central Java, Indonesia*, Semarang, Indonesia: EAI; 2023. https://doi.org/10.4108/eai.29-6-2022.2326103
31. Yudhistira D. *Development of a special preparation period physical training model to improve power, agility and endurance in senior kumite karateka* [Doctoral dissertation]. Yogyakarta: Universitas Negeri Yogyakarta, Faculty of Sport Sciences and Health; 2023.
32. Zemková E. Differential contribution of reaction time and movement velocity to the agility performance reflects sport-specific demands. *Human Movement*, 2018;17(2): 94–101. https://doi.org/10.1515/humo-2016-0013
33. Cherepov EA, Eganov AV, Bakushin AA, Platunova NYa, Sevostyanov DYu. Maintaining postural balance in martial arts athletes depending on coordination abilities. *Journal of Physical Education and Sport*, 2021;21(6):3427-3432. https://doi.org/10.7752/jpes.2021.06464
34. Akuthota V, Ferreiro A, Moore T, Fredericson M. Core Stability Exercise Principles: *Current Sports Medicine Reports*, 2008;7(1): 39–44. https://doi.org/10.1097/01.CSMR.0000308663.13278.69
35. Nipa SI, Sriboonreung T, Paungmali A, Phongnarisorn C. The Effects of Pelvic Floor Muscle Exercise Combined with Core Stability Exercise on Women with Stress Urinary Incontinence following the Treatment of Nonspecific Chronic Low Back Pain. Gyftopoulos K (ed.) *Advances in Urology*, 2022;2022: 1–8. https://doi.org/10.1155/2022/2051374
36. Jo SH, Choi HJ, Cho HS, Yoon JH, Lee WY. Effect of Core Balance Training on Muscle Tone and Balance Ability in Adult Men and Women. *International Journal of Environmental Research and Public Health*, 2022;19(19): 12190. https://doi.org/10.3390/ijerph191912190
37. Chaabène H, Hachana Y, Franchini E, Mkaouer B, Chamari K. Physical and Physiological Profile of Elite Karate Athletes: *Sports Medicine*, 2012;42(10): 829–843. https://doi.org/10.2165/11633050-000000000-00000
38. Bažant M. *Physics principles in karate* [Bachelor thesis]. Brno: Masaryk University, Faculty of Education; 2025.
39. Gronwald T, Törpel A, Herold F, Budde H. Perspective of Dose and Response for Individualized Physical Exercise and Training Prescription. *Journal of Functional Morphology and Kinesiology*, 2020;5(3): 48. https://doi.org/10.3390/jfmk5030048

40. Zubin Maslov P, Schulman A, Lavie CJ, Narula J. Personalized exercise dose prescription. *European Heart Journal*, 2018;39(25): 2346–2355. https://doi.org/10.1093/eurheartj/ehx686
41. Balyi I, Way R. Long-term athlete development. *Choice Reviews Online*, 2014;51(09): 51-5081-51–5081. https://doi.org/10.5860/CHOICE.51-5081.
42. Gholami A, Mousavi SM, Naeimikia M, Sofizadeh P. The effect of game-based karate training on the learning of basic techniques and enjoyment of physical activity in children. *Journal of Physical Education*, 2024;35(1). https://doi.org/10.4025/jphyseduc.v35i1.3506
43. Lloyd RS, Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength & Conditioning Journal*, 2012;34(3): 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea
44. Myer GD, Faigenbaum AD, Ford KR, Best TM, Bergeron MF, Hewett TE. When to Initiate Integrative Neuromuscular Training to Reduce Sports-Related Injuries and Enhance Health in Youth?: *Current Sports Medicine Reports*, 2011;10(3): 155–166. https://doi.org/10.1249/JSR.0b013e31821b1442

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ORIGINAL ARTICLE

Evaluation of integrated sprint and plyometric interventions for enhancing spatial performance of sprinters

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Abstract

Background and Study Aim: Sprint performance is strongly influenced by neuromuscular coordination and spatial running mechanics. Sprint training commonly includes speed work together with strength and plyometric exercises. Although these approaches are used in practice, their relative effectiveness in improving key spatial sprint parameters remains of practical interest. Therefore, the present study sought to investigate the effects of a ten-week integrated sprint and plyometric training programme on selected key spatial sprint-related parameters in male sprinters.

Material and Methods: The experimental group underwent sprint and plyometric training three times a week, while the control group followed their normal sprint training schedule. Ground contact time, step length, stride length, and 30 m sprint time were assessed at baseline and after the intervention. Data were analyzed using mixed analysis of variance (ANOVA) and analysis of covariance (ANCOVA), in which body mass index (BMI) was entered as a covariate.

Results: The experimental group showed a statistically significant decrease in ground contact time and sprint time, while showing a significant increase in step length and stride length during the pre- to post-assessment period ($p < 0.001$). In contrast, no statistically significant changes in any spatial parameters were recorded for the control group over the same period ($p > 0.05$). Pronounced time × group interactions were observed for the examined spatial parameters ($p \leq 0.005$).

Conclusions: Integrated sprint and plyometric training is associated with beneficial adaptations relevant to sprint performance in male sprinters. This approach reflects coordinated neuromuscular and mechanical responses during sprint execution and supports its practical application in training settings.

Keywords: plyometrics, ground contact time, stride mechanics, neuromuscular adaptations, sprinters

Introduction

Sprint performance represents a complex motor task that depends on the coordination of multiple biomechanical and physiological processes during high-speed running. Effective sprinting requires the precise interaction of force production, limb positioning, and temporal control of ground contact in order to maintain forward acceleration and running efficiency. Small variations in step and stride characteristics can substantially influence running velocity and movement economy, making spatial parameters an important component of performance evaluation. Consequently, training strategies that simultaneously address mechanical execution and neuromuscular control are of practical importance in sprint preparation and require detailed examination in applied training contexts.

Sprint performance is fundamentally based on neuromuscular readiness and the efficiency of sprint biomechanics, through which small changes in spatial variables can cause substantial changes in competitive outcomes. Contemporary sprint research consistently emphasizes that speed development cannot be achieved only by sprinting but requires an integrated programming paradigm that aims to advance acceleration capacity, maximal velocity mechanics, and the neuromuscular determinants of force application [1, 2]. From an applied perspective, this premise is especially relevant in resource-constrained training settings in which coaches seek field-based measurements and practical interventions to monitor parameters such as ground contact time, step length, stride length, and total sprint time.

Within this applied context, warm-up interventions are an important and often under optimized element of sprint preparation. Beyond simply preventing injuries, warm-ups can acutely improve explosive capacity by increasing muscle

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temperature, improving nerve conduction velocity, and enhancing coordination of movement, leading to better sprint-specific movement execution. Conditioning activities incorporating sprint drills and explosive exercises have been demonstrated to create acute performance effects in sprinters, supporting the idea that the warm-up is a performance intervention rather than a procedural formality [3]. Because of the similarities in key mechanical characteristics between plyometric actions and sprinting (rapid stretch-shortening cycle function and a high rate of force development), warm-up practices using plyometric-type activation may be particularly relevant for improving sprint output immediately and over time [4].

Training theory further supports the incorporation of plyometric content into sprint development plans because both modalities focus on overlapping neuromuscular qualities. Long-term strength-oriented approaches have shown benefits in sprint-related tasks, such as change-of-direction speed and sprint performance, suggesting that increased force production capacity aids faster and more efficient sprinting patterns [5,6]. At the same time, elite sprint development frameworks emphasize that the "best practice" approach is integrated and periodized, progressing from technical learning and capacity development toward higher-intensity sprint-specific outputs as the athlete adapts [7]. This theoretical perspective provides a rationale for a combined sprint and plyometric program in which specific, systematic, and progressive attention is given to mechanics (step and stride characteristics) and neuromuscular function (ground contact behavior and acceleration capacity).

Empirical evidence related to plyometric training shows improvements in explosive performance across a range of sporting disciplines. Meta-analyses and systematic reviews suggest that plyometric-based interventions can produce gains in sprint performance along with increases in jumping ability [8, 9]. The benefits in sprinting resulting from plyometric practice are mediated by mechanisms related to spatial parameters: regulation of muscle contractility during movement, increased impulse generation over a short time period, and improved coordination of elastic energy storage and release during the stretch and relaxation phases of muscle action. These adaptations can reduce ground contact time while supporting greater step and stride lengths for a given velocity [10, 11]. Continuous improvement in sprint time is attractive to practitioners because it indicates a viable way to achieve performance enhancement through measurable alterations in the interaction between the athlete and the ground.

Assessing training effects requires the adoption of appropriate measurement approaches. Although sophisticated equipment, such as force plates, timing gates, and inertial measurement units, provides high-resolution data, many sprint programmes rely on more practical field methods. Empirical evidence suggests that meaningful changes in technique and performance can be assessed through step kinematic analyses and periodized monitoring schemes, supporting the use of structured pre- and post-measurements in applied settings [12, 13]. This aligns with the assessment of spatial parameters that can be quantified using practicable tools while remaining consistent with established constructs of sprint performance.

From a performance-oriented standpoint, sprint and plyometric training are commonly associated with changes in ground contact time, step and stride characteristics, and overall sprint time. Previous syntheses indicate that plyometric training improves physical performance outcomes across populations, supporting the expectation of measurable change following structured training [14, 15]. Moreover, acute and post-activation approaches, particularly those combining resisted sprinting and explosive tasks, have received attention for improving acceleration and short-distance sprint outputs, suggesting an additional pathway through which integrated training may affect spatial parameters [16, 17].

Several aspects remain under discussion in applied sprint training research. Many studies examine sprint training, strength training, or plyometric training in isolation, whereas coaches frequently employ combined programmes in practical settings [18, 19]. In addition, even when improvements in sprint time are reported, spatial parameter responses, particularly contact-time behavior and step and stride adaptations, are not always presented in a way that supports applied coaching decisions. Ongoing investigations also address questions related to training dose, retention, and transfer of plyometric adaptations to sprint performance, highlighting the need for applied studies that include clear biomechanical indicators [20, 21].

Analysis of research findings has shown that sprint performance is influenced by the interaction of neuromuscular control and spatial running mechanics, and that training approaches frequently combine sprint and plyometric elements. Researchers emphasize that measurable changes in contact behavior and step–stride characteristics are central to understanding performance adaptations in applied settings. At the same time, the interpretation of these parameters in practical training contexts remains methodologically and practically complex. This situation highlights the relevance of further structured examination of spatial sprint characteristics within integrated training conditions.

Materials and Methods

Participants

A total of one hundred male sprinters volunteered to take part in the study. Participants came from university-level sprint training programmes and had already participated in structured sprint training.

The inclusion criteria were:

- age between 18 and 25 years;
- a minimum of 1 year of regular sprint training experience;
- active participation in sprint training at the time of recruitment;
- no musculoskeletal injuries or neurological disorders within the 6 months prior to the study.

Participants were excluded if they had:

- a history of lower limb surgery;
- a current injury;
- participation in additional structured strength or plyometric training programmes alongside regular sprint training during the study period.

Baseline demographic characteristics recorded were age, body height, body mass, and body mass index. All participants were classified as university-level competitive sprinters and regularly participated in organized training and competition. Prior to data collection, participants were familiarized with the testing procedures to reduce learning effects.

Ethical approval was obtained in accordance with the guidelines of the Research Performance Evaluation Committee (RPEC) of Gomal University, Dera Ismail Khan, Pakistan. The performance testing and training procedures consisted of non-invasive field-based assessments commonly used in routine sports practice. All participants were informed about the study objectives, procedures, and possible risks and benefits, and provided written informed consent prior to participation. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Research Design

The study used a two-group pre-test–post-test controlled experimental design. Participants completed baseline (pre-test) measurements, followed by a 10-week training period and post-test measurements. The confirmatory inferential framework was the Group × Time interaction. This interaction was used to determine whether pre-to-post change differed between the experimental and control groups. The 10-week integrated sprint technique and plyometric training program is presented in Table 1. The training frequency was three sessions per week. Session duration was 45–

Table 1. 10-Week integrated sprint technique and plyometric training program (ISTPTP)

Weeks	Training Phase	Main Focus	Sprint Technique Drills (Volume)	Plyometric Exercises (Volume)	Sprint Work (Volume & Intensity)	Rest & Supervision
1–2	Adaptation	Technique learning & neuromuscular adaptation	Wall drills, A-skips, high knees; 2–3 sets × 20–30 m	Squat jumps, ankling; 2–3 sets × 8–10 reps	3 × 20 m @ 85–90%	Rest: 60–90 s (drills), 2–3 min (sprints); supervised by sprint coach
3–4	Technique Development	Improved sprint mechanics	Marching drills, skipping; 3 sets × 20–30 m	Bounding, CMJ; 3 sets × 6–8 reps	4 × 20 m @ 90%	Rest: 90 s (plyometrics), 3 min (sprints); coach monitored technique
5–6	Strength–Power	Force application & elastic energy use	Fast-leg drills; 3 sets × 30 m	Box jumps, pogo jumps; 3–4 sets × 6–8 reps	4 × 30 m @ 95%	Rest: 2 min (plyometrics), 3–4 min (sprints); verbal feedback provided
7–8	Reactive & Speed	Reduced ground contact time	Fast-leg drills; 3 sets × 30 m	Hurdle hops, drop jumps; 3–4 sets × 5–6 reps	Flying sprints (20 + 20 m) × 3	Rest: 2–3 min (plyometrics), 4 min (sprints); close supervision
9–10	Performance	Sprint performance optimization	Technique reinforcement; 2–3 sets × 30 m	Mixed plyometrics; 3 sets × 6 reps	3 × 30 m @ 95–100%	Rest: 3 min (plyometrics), 4–5 min (sprints); full supervision

60 minutes. The program applied the principles of specificity, progressive overload, recovery, and variation.

Group Assignment

Following baseline testing, participants were assigned to one of two groups: an experimental group (N = 60) or a control group (N = 40) using a matched-group allocation procedure based on baseline 30 m sprint time to ensure equivalence in initial sprint performance (Figure 1). The experimental group followed a ten-week integrated sprint and plyometric training programme, while the control group followed their usual sprint training programme without additional plyometric exercises.

After completing the intervention, complete post-test data were collected from 46 participants in the experimental group and all 40 participants in the control group. Attrition in the experimental group (n = 14) was attributed to non-training-related factors such as scheduling conflicts and inconsistent attendance. No training-associated injuries or adverse events were reported during the intervention period.

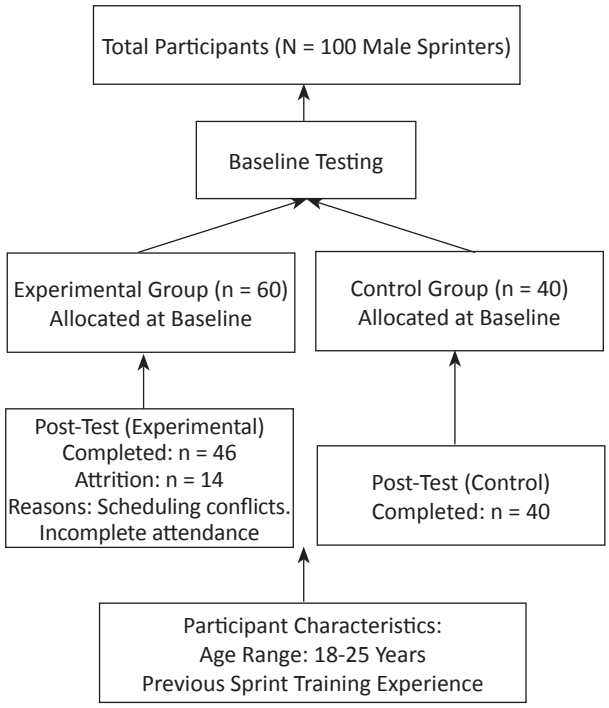

Figure1. ParticipantFlowDiagram

Procedure

All testing sessions and the intervention in the form of training were held at the Gomal Football Ground, Gomal University campus, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. The training and testing surface was a natural turf football pitch, which was consistent throughout the study period to ensure consistent ground conditions for sprinting assessments. A group of local and international researchers conducted the project. Participants reported to the field between 16:00 and 18:00 h to minimize the effects of circadian factors on performance. Weather conditions were monitored during testing and training sessions, and dry and warm conditions (around 22–28 °C) were maintained in most sessions. Sessions affected by adverse weather were rescheduled to maintain consistency.

Upon arrival, the participants were familiarized with the study procedures and underwent a standardized dynamic warm-up protocol lasting approximately 10–12 minutes. The warm-up consisted of light jogging, dynamic stretching, sprinting drills, and progressive acceleration runs. Immediately after the warm-up phase, the participants performed 3 maximal-effort 30-m sprints along a marked straight line on the football ground, with 3–5 min of passive recovery between trials to reduce fatigue. Participants wore sprint training footwear that they normally used during all sessions.

Sprint spatiotemporal parameters were obtained using high-speed video recorded with a smartphone camera (iPhone 12, Apple Inc., USA) positioned perpendicular to the sprint lane at a distance of about 8 m. Videos were captured at 240 frames per second (fps) and then analyzed frame-by-frame using Kinovea motion analysis software (version 0.9.5) to detect periods of ground contact and flight. Sprint time was also measured using a calibrated manual stopwatch. Step length and stride length were measured using visual footprint markers made on the turf and a standardized measuring tape. All assessments were carried out by the same experienced investigator to ensure procedural consistency and reliability.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics (version 27). Data were screened prior to inferential analysis. Univariate outliers were examined using standardized z-scores, and multivariate outliers were assessed using Mahalanobis distance. No influential cases requiring removal were identified. Missing data occurred only at post-test due to participant attrition (14%). Little's MCAR test indicated that missingness was not systematic. Analyses were therefore conducted using a complete-case (per-protocol) approach including participants with both pre- and post-test measurements. No imputation procedures were applied. The primary outcome variable was 30-m sprint time, and secondary outcomes included ground contact time, step length, and stride length. Descriptive statistics (mean ± standard deviation) were calculated for each variable by group and time point. The study hypothesis was tested using a two-way mixed-design analysis of variance (ANOVA), with (1) Group (experimental vs control) as the between-subject factor and (2) Time (pre-test vs

post-test) as the within-subject factor. The primary confirmatory test was the Group × Time interaction term, and a statistically significant interaction ($p < .05$) was interpreted as evidence that pre-to-post change differed between groups. To adjust for baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was additionally performed for each outcome, with baseline sprint time and body mass index (BMI) included as covariates. Confirmatory inference remained based exclusively on the Group × Time interaction in the ANCOVA model. Model assumptions were evaluated prior to interpretation, including normality of residuals (Shapiro–Wilk test) and homogeneity of variance (Levene's test), and for ANCOVA models homogeneity of regression slopes was assessed. Effect sizes were reported as partial eta-squared (ηp^2) for ANOVA and ANCOVA effects. Statistical significance was set at $p < .05$ (two-tailed). Within-group paired comparisons were not used as primary inferential evidence and were not considered confirmatory tests of the study hypothesis.

Results

The results of missing data screening and univariate characteristics of the study variables are presented in Table 2. Complete baseline data were available for all variables. Post-test data were missing for 14 participants (14%) due to attrition. Little's MCAR test indicated that missingness was not systematic. Analyses were therefore conducted using a complete-case approach.

The univariate descriptive statistics of demographic and spatial parameters are presented in Table 3. Residual and influence diagnostics were examined prior to inferential testing. No cases exceeded commonly accepted thresholds for exclusion, and all observations were retained for analysis.

Prior to inferential analysis, model assumptions were evaluated (Table 4). Normality of residuals

Table 2. Little MCAR test

Variable Name	N	Mean	SD	Missing (n)	Missing (%)	Outliers (Low)	Outliers (High)
Age (years)	100	21.10	1.80	0	0.0	0	5
Height (cm)	100	175.09	6.09	0	0.0	0	0
Body Mass (kg)	100	68.23	6.57	0	0.0	0	0
Ground Contact Time – Pre (ms)	100	142.74	11.56	0	0.0	0	0
Step Length – Pre (m)	100	1.85	0.12	0	0.0	0	1
Stride Length – Pre (m)	100	3.70	0.26	0	0.0	0	1
Sprint Time – Pre (s)	100	4.92	0.40	0	0.0	0	0
Ground Contact Time – Post (ms)	86	139.67	11.81	14	14.0	1	2
Step Length – Post (m)	86	1.89	0.13	14	14.0	0	1
Stride Length – Post (m)	86	3.80	0.27	14	14.0	0	1
Sprint Time – Post (s)	86	4.79	0.43	14	14.0	0	0
Group (1 = experimental, 2 = control)	100	—	—	0	0.0	—	—

Table 3. Univariate descriptive statistics of demographic and spatial parameters

Statistic	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.72	2.04	1.48	0.491	84
Standardized Predicted Value	−1.534	1.138	0.000	1.000	84
Standard Error of Predicted Value	0.021	0.054	0.035	0.009	84
Adjusted Predicted Value	0.67	2.04	1.48	0.495	84
Residual	−0.238	0.278	0.000	0.105	84
Standardized Residual	−2.162	2.519	0.000	0.951	84
Studentized Residual	−2.311	2.740	0.004	1.027	84
Deleted Residual	−0.272	0.328	0.001	0.122	84
Studentized Deleted Residual	−2.382	2.869	0.005	1.041	84
Mahalanobis Distance	2.082	18.848	7.905	4.363	84
Cook's Distance	0.000	0.152	0.020	0.031	84
Centered Leverage Value	0.025	0.227	0.095	0.053	84

was assessed using the Shapiro–Wilk test. Although minor deviations from normality were observed for selected variables within the control group, the mixed-design ANOVA and ANCOVA procedures are considered robust to moderate violations of normality, particularly with comparable group sizes. Homogeneity of variance was assessed using Levene's test, and no substantial violations were detected. Where appropriate, the Greenhouse–Geisser correction was applied to adjust for violations of sphericity. Overall, model assumptions were considered adequately satisfied for parametric analysis.

Table 5 presents the overall pre- and post-test descriptive statistics for the spatial parameters. Ground contact time decreased, whereas step length and stride length increased. Sprint time decreased at post-test. Post-test sample size was reduced due to attrition (n = 84).

Table 6 presents the pre- and post-test descriptive statistics for the experimental group. Ground contact time decreased, whereas step length and stride length increased. Sprint time decreased at post-test. Post-test sample size was reduced to n = 44 due to attrition.

Table 7 presents the pre- and post-test descriptive statistics for the control group. No meaningful changes were observed between pre- and post-test values across the measured variables.

Baseline equivalence between the experimental

Table 4. Results of Kolmogorov–Smirnov and Shapiro–Wilk tests

Variable	Group	Kolmogorov–Smirnov			Shapiro–Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Ground Contact Time (Estimated) – Pre (ms)	Experimental	.156	46	.009	.957	46	.105
	Control	.150	40	.023	.948	40	.065
Step Length – Pre (m)	Experimental	.094	46	.200*	.981	46	.654
	Control	.122	40	.134	.950	40	.077
Stride Length – Pre (m)	Experimental	.071	46	.200*	.980	46	.646
	Control	.145	40	.034	.932	40	.018
Sprint Time (30 m) – Pre (s)	Experimental	.100	46	.200*	.968	46	.256
	Control	.070	40	.200*	.983	40	.801
Ground Contact Time (Estimated) – Post (ms)	Experimental	.079	46	.200*	.976	46	.476
	Control	.150	40	.023	.948	40	.066
Step Length – Post (m)	Experimental	.089	46	.200*	.982	46	.705
	Control	.121	40	.140	.949	40	.073
Stride Length – Post (m)	Experimental	.089	46	.200*	.974	46	.401
	Control	.146	40	.035	.932	40	.018
Sprint Time (30 m) – Post (s)	Experimental	.100	46	.200*	.975	46	.433
	Control	.070	40	.200*	.983	40	.804

Note. * This is a lower bound of the true significance; a. Lilliefors significance correction.

Table 5. Descriptive statistics of spatial parameters

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	100	142.80	11.67	86	139.80	11.86
Step Length (m)	100	1.85	0.12	86	1.89	0.13
Stride Length (m)	100	3.69	0.26	86	3.79	0.27
Sprint Time (30 m) (s)	100	4.91	0.39	86	4.79	0.43

Table 6. Descriptive statistics of spatial parameters in the experimental group

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	60	141.47	12.21	46	135.32	11.15
Step Length (m)	60	1.85	0.13	46	1.93	0.14
Stride Length (m)	60	3.69	0.28	46	3.88	0.27
Sprint Time (30 m) (s)	60	4.84	0.36	46	4.60	0.32

and control groups at pre-test was examined using independent-samples t-tests (Table 8). H0: There is no statistically significant difference between the experimental and control groups at pre-test for the measured spatial sprint parameters. No statistically significant differences were observed for ground contact time, step length, or stride length ($p > .05$). However, a statistically significant baseline difference was detected for 30-m sprint time ($p = .030$), with the experimental group demonstrating a modestly faster pre-test time (Cohen's $d = -0.45$). Therefore, baseline sprint time was included as a covariate in subsequent ANCOVA analyses.

Descriptive statistics for both groups at pre- and post-test are presented in Table 9. The effect of the intervention on 30-m sprint performance was examined using a two-way mixed-design analysis of variance (ANOVA) (Table 10). H1: It was hypothesized that pre-to-post changes in 30-m sprint performance would differ between the experimental and control groups (i.e., a significant Group × Time interaction would be observed). The analysis was conducted with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor. The analysis revealed a significant main effect of Time, $F(1.06, 86.60) = 12717.04$, $p < .001$, $\eta p^2 = .994$, and a significant main effect of Group, $F(1, 82) = 5.00$, $p = .028$, $\eta p^2 = .057$. A statistically significant Group × Time interaction was observed, $F(1.06, 86.60) = 8.31$, $p = .004$, $\eta p^2 = .092$. The study hypothesis was tested using the Group × Time interaction term. Because

Table 7. Descriptive statistics of spatial parameters in the control group

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	40	144.73	10.71	40	144.72	10.72
Step Length (m)	40	1.85	0.10	40	1.85	0.10
Stride Length (m)	40	3.70	0.24	40	3.70	0.24
Sprint Time (30 m) (s)	40	5.02	0.43	40	5.02	0.43

Table 8. Results of independent samples t-test

Variable	Experimental group (n = 60) Mean ± SD	Control group (n = 40) Mean ± SD	t (df)	p-value	Cohen's d
Ground Contact Time – Pre (ms)	141.47 ± 12.21	144.73 ± 10.71	−1.36 (96)	.176	−0.28
Step Length – Pre (m)	1.85 ± 0.13	1.85 ± 0.10	0.06 (96)	.951	0.01
Stride Length – Pre (m)	3.69 ± 0.28	3.70 ± 0.24	−0.14 (96)	.886	−0.03
Sprint Time (30 m) – Pre (s)	4.84 ± 0.36	5.02 ± 0.43	−2.20 (96)	.030	−0.45

Table 9. Descriptive statistics of spatial parameters

Variable	Experimental group (n = 44)	Control (group n = 40)
Ground Contact Time – Pre (ms)	143.61 ± 12.04	144.73 ± 10.71
Ground Contact Time – Post (ms)	135.32 ± 11.15	144.72 ± 10.72
Step Length – Pre (m)	1.87 ± 0.13	1.85 ± 0.10
Step Length – Post (m)	1.93 ± 0.14	1.85 ± 0.10
Stride Length – Pre (m)	3.74 ± 0.27	3.70 ± 0.24
Stride Length – Post (m)	3.88 ± 0.27	3.70 ± 0.24
Sprint Time (30 m) – Pre (s)	4.86 ± 0.34	5.02 ± 0.43
Sprint Time (30 m) – Post (s)	4.58 ± 0.32	5.02 ± 0.43

Table 10. Mixed ANOVA results for spatial parameters

Effect	F	df	p	Partial η^2
Time	12717.04	1.06, 86.60	< .001	.994
Group	5.00	1, 82	.028	.057
Time × Group	8.31	1.06, 86.60	.004	.092

Note. Greenhouse–Geisser correction applied due to violation of sphericity.

the interaction effect was statistically significant, the null hypothesis was rejected, indicating that the pre-to-post change differed between the experimental and control groups.

To facilitate interpretation of the interaction effect, the estimated marginal means across time for both groups are presented in Figure 2. The figure visually reflects the statistically significant Group × Time interaction.

To control for baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was performed with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor. Baseline sprint time and body mass index (BMI) were included as covariates. H1: It was hypothesized that, after controlling baseline sprint time and BMI, pre-to-post changes in 30-m sprint performance would differ between the experimental and control groups. Descriptive statistics for both groups are presented in Table 11, and the ANCOVA results are presented in Table 12.

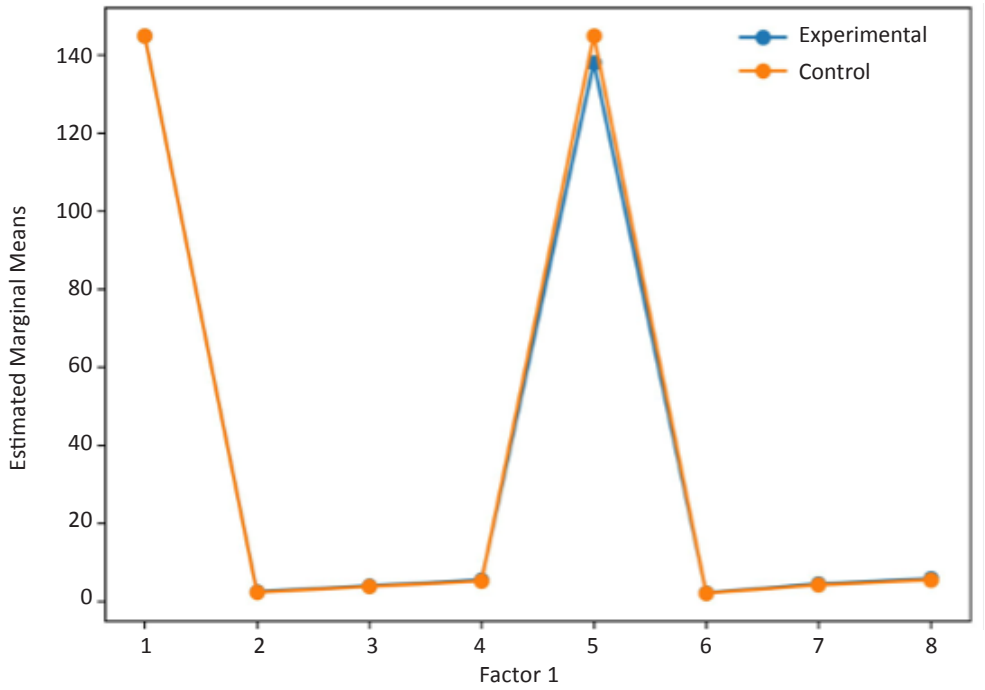

Figure 2. Estimated marginal means of spatial parameters across time (pre- and post-test) for experimental and control groups.

Table 11. Descriptive statistics of spatial parameters (Adjusted analysis sample)

Variable	Experimental group (n = 44)	Control group (n = 40)
Ground Contact Time – Pre (ms)	143.61 ± 12.04	144.73 ± 10.71
Ground Contact Time – Post (ms)	135.32 ± 11.15	144.72 ± 10.72
Step Length – Pre (m)	1.87 ± 0.13	1.85 ± 0.10
Step Length – Post (m)	1.93 ± 0.14	1.85 ± 0.10
Stride Length – Pre (m)	3.74 ± 0.27	3.70 ± 0.24
Stride Length – Post (m)	3.88 ± 0.27	3.70 ± 0.24
Sprint Time (30 m) – Pre (s)	4.86 ± 0.34	5.02 ± 0.43
Sprint Time (30 m) – Post (s)	4.58 ± 0.32	5.02 ± 0.43

Table 12. Mixed ANCOVA results for spatial parameters

Effect	F	df	p	Partial η²
Time	117.11	1.06, 85.51	< .001	.591
BMI (covariate)	0.02	1, 81	.967	.000
Group	4.93	1, 81	.029	.057
Time × Group	8.23	1.06, 85.51	.005	.092

Note. Greenhouse–Geisser correction applied due to violation of sphericity.

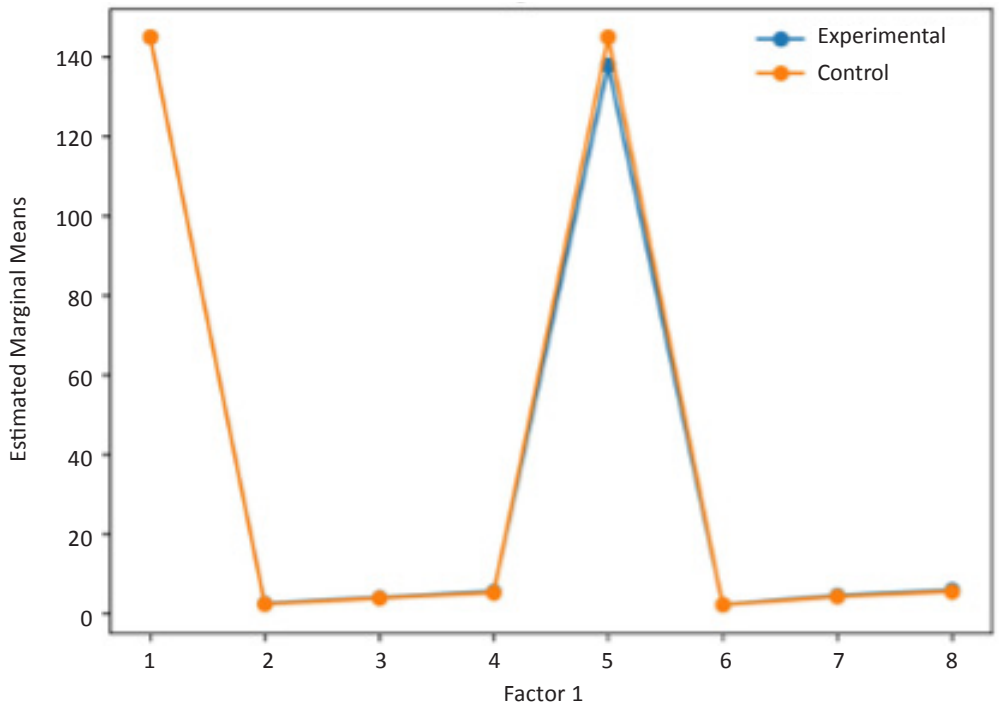

Figure 3. Estimated marginal means of spatial parameters adjusted for body mass index (BMI). Note. Covariates appearing in the model are evaluated at the following values: Body mass of participant (kg) = 67.937

To adjust for minor baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was conducted with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor, while baseline sprint time and body mass index (BMI) were included as covariates. Descriptive statistics corresponding to this analysis are presented in Table 11. The ANCOVA results are presented in Table 12. The analysis revealed a significant main effect of Time, $F(1.06, 85.51) = 117.11$, $p < .001$, $\eta p^2 = .591$, and a significant main effect of Group, $F(1, 81) = 4.93$, $p = .029$, $\eta p^2 = .057$. The covariate BMI was not statistically significant, $F(1, 81) = 0.02$, $p = .967$, $\eta p^2 = .000$. A statistically significant Group × Time interaction was observed, $F(1.06, 85.51) = 8.23$, $p = .005$, $\eta p^2 = .092$. The study hypothesis was tested using the Group × Time interaction term in the mixed ANCOVA model. Because the interaction effect was statistically significant, the null hypothesis was rejected, indicating that the adjusted pre-to-post change differed between the experimental and control groups after controlling for baseline sprint time and BMI.

To illustrate the adjusted model results, the estimated marginal means are presented in Figure 3. Figure presents the estimated marginal means adjusted for BMI and reflects the statistically significant Group × Time interaction.

Discussion

The present study examined the effects of a 10-week integrated sprint and plyometric training program on selected spatiotemporal parameters of sprint performance in male university-level sprinters. The primary finding was a statistically significant Group × Time interaction for 30-m sprint time, ground contact time, step length, and stride length, indicating that pre-to-post changes differed between the experimental and control groups. These results indicate that the integrated intervention produced performance adaptations that exceeded those observed in athletes who continued usual sprint training alone.

The experimental group demonstrated reductions in ground contact time and sprint time, along with increases in step and stride length, whereas the control group showed minimal change across the same period. These findings suggest that the integrated training program was associated with measurable alterations in sprint spatiotemporal characteristics beyond those observed with usual sprint training alone. From a performance perspective, sprint velocity over short distances is determined by the interaction between step length and step frequency, with ground contact time representing a critical determinant of effective horizontal force production. The reduction in ground contact time observed in the experimental group, combined with concurrent increases in step and stride length, suggests improved mechanical efficiency during the stance phase.

The reduction in ground contact time and the concurrent increases in step and stride length are consistent with patterns reported in previous sprint and plyometric training studies [4, 11, 22]. Prior literature has proposed that such changes may reflect

improvements in sprint mechanics and lower-limb power characteristics. Although the present study did not directly measure neuromuscular variables or force production, the observed spatiotemporal modifications align with adaptations previously documented following plyometric interventions. Similar kinematic patterns have been reported following speed-oriented interventions in which enhanced stretch–shortening cycle function and rate of force development contributed to shorter contact phases without compromising step amplitude [4, 10, 11, 22, 23].

Similarly, the observed reduction in 30-m sprint time in the experimental group is consistent with meta-analytic evidence indicating performance improvements following plyometric or combined sprint training programs in athletic populations [4, 24]. The present findings therefore extend previous work by demonstrating comparable adaptations within a university-level sprint cohort under field-based conditions. The magnitude of the interaction effect indicates practically meaningful change rather than trivial statistical variation, and supports the effectiveness of systematic integration of sprint drills and progressive plyometric content within the same microcycle.

Baseline analyses indicated general equivalence between groups, except for a modest difference in pre-test sprint time. This difference was statistically controlled in subsequent ANCOVA models. The persistence of significant Group × Time interactions after covariate adjustment supports the robustness of the observed group differences over time. Although regression to the mean cannot be completely excluded, the adjusted results strengthen confidence that the improvements were primarily attributable to the intervention. Similar statistical adjustment procedures have been recommended in training-intervention research where baseline performance asymmetry is present [7, 12].

Attrition during the intervention period was limited and unrelated to injury. Diagnostic analyses indicated no influential outliers affecting model stability. Additionally, the relative stability of performance in the control group strengthens the internal validity of the comparison by reducing the likelihood that changes in the experimental group were attributable to repeated testing or natural performance fluctuation. Comparable stability of sprint performance in non-intervention conditions has been reported in longitudinal training studies when no additional neuromuscular stimulus is introduced beyond habitual practice [5, 6].

Study Limitations and Future Directions

Several limitations should be acknowledged. First, neuromuscular activation, force production, musculotendinous stiffness, and other biomechanical determinants were not directly measured; therefore, mechanistic explanations for the observed changes remain speculative. Sprint time was measured using manual timing and spatiotemporal parameters were derived from smartphone-based high-speed video analysis, which may introduce observer-related variability compared with automated systems. The sample consisted of male university-level sprinters, which may limit generalizability to other populations and surface conditions.

Future research should incorporate direct biomechanical and neuromuscular measurements, examine longer intervention durations, include retention testing, and evaluate similar training models across different competitive levels and female athletes to further clarify mechanisms and external validity.

Conclusions

The present study evaluated the effects of a 10-week integrated sprint and plyometric training program on selected spatiotemporal parameters of sprint performance in male university-level sprinters. Statistically significant Group × Time interactions were observed for 30-m sprint time, ground contact time, step length, and stride length, indicating that pre-to-post changes differed between the experimental and control groups. Participants in the experimental group demonstrated greater changes in sprint time and associated spatiotemporal variables compared with those following usual sprint training. These findings suggest that the integrated training program was associated with measurable alterations in sprint performance characteristics under the conditions examined in this study. The conclusions are based solely on the measured spatiotemporal outcomes. Mechanistic factors such as neuromuscular activation, force production, or musculotendinous properties were not directly assessed and therefore cannot be inferred from the present data. Within the limitations of this sample and study design, the results indicate that combining sprint and plyometric exercises over a 10-week period may be associated with greater improvements in sprint-related spatiotemporal parameters than usual sprint training alone. Further research incorporating direct biomechanical measurements, alternative training comparators, and diverse athletic populations is warranted to clarify underlying mechanisms and generalizability.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. Dasteridis G, Piliandis T, Mantzouranis N. The effect of different strength training programmes on young athletes' sprint performance. *Stud Phys Cult Tourism*, 2011;18(2): 141–147.
2. Rumpf MC, Lockie RG, Cronin JB, Jalilvand F. Effect of Different Sprint Training Methods on Sprint Performance Over Various Distances: A Brief Review. *Journal of Strength and Conditioning Research*, 2016;30(6): 1767–1785. https://doi.org/10.1519/JSC.0000000000001245
3. Yoshimoto T, Takai Y, Kanehisa H. Acute effects of different conditioning activities on running performance of sprinters. *SpringerPlus*, 2016;5(1): 1203. https://doi.org/10.1186/s40064-016-2860-7
4. Sáez De Villarreal E, Requena B, Cronin JB. The Effects of Plyometric Training on Sprint Performance: A Meta-Analysis. *Journal of Strength and Conditioning Research*, 2012;26(2): 575–584. https://doi.org/10.1519/JSC.0b013e318220fd03
5. Keiner M, Sander A, Wirth K, Schmidtbleicher D. Long-Term Strength Training Effects on Change-of-Direction Sprint Performance. *Journal of Strength and Conditioning Research*, 2014;28(1): 223–231. https://doi.org/10.1519/JSC.0b013e318295644b
6. Styles WJ, Matthews MJ, Comfort P. Effects of Strength Training on Squat and Sprint Performance in Soccer Players. *Journal of Strength and Conditioning Research*, 2016;30(6): 1534–1539. https://doi.org/10.1519/JSC.0000000000001243
7. Haugen T, Seiler S, Sandbakk Ø, Tønnessen E. The Training and Development of Elite Sprint Performance: an Integration of Scientific and Best Practice Literature. *Sports Medicine - Open*, 2019;5(1): 44. https://doi.org/10.1186/s40798-019-0221-0
8. Booth MA, Orr R. Effects of Plyometric Training on Sports Performance. *Strength & Conditioning Journal*, 2016;38(1): 30–37. https://doi.org/10.1519/SSC.0000000000000183
9. Krakan I, Milanovic L, Belcic I. Effects of Plyometric and Repeated Sprint Training on Physical Performance. *Sports*, 2020;8(7): 91. https://doi.org/10.3390/sports8070091
10. Maćkała K, Fostiak M. Acute Effects of Plyometric Intervention—Performance Improvement and Related Changes in Sprinting Gait Variability. *Journal of Strength and Conditioning Research*, 2015;29(7): 1956–1965. https://doi.org/10.1519/JSC.0000000000000853
11. Mackala K, Fostiak M, Schweyen B, Osik T, Coch M. Acute Effects of a Speed Training Program on Sprinting Step Kinematics and Performance. *International Journal of Environmental Research and Public Health*, 2019;16(17): 3138. https://doi.org/10.3390/ijerph16173138
12. Bezodis IN, Kerwin DG, Cooper SM, Salo AIT. Sprint Running Performance and Technique Changes in Athletes During Periodized Training: An Elite Training Group Case Study. *International Journal of Sports Physiology and Performance*, 2018;13(6): 755–762. https://doi.org/10.1123/ijspp.2017-0378
13. Nuell S, Illera-Domínguez VíctorR, Carmona G, Alomar X, Padullés JM, Lloret M, et al. Hypertrophic muscle changes and sprint performance enhancement during a sprint-based training macrocycle in national-level sprinters. *European Journal of Sport Science*, 2020;20(6): 793–802. https://doi.org/10.1080/17461391.2019.1668063
14. Kons RL, Orssatto LBR, Ache-Dias J, De Pauw K, Meeusen R, Trajano GS, et al. Effects of Plyometric Training on Physical Performance: An Umbrella Review. *Sports Medicine - Open*, 2023;9(1): 4. https://doi.org/10.1186/s40798-022-00550-8
15. Xie L, Chen J, Dai J, Zhang W, Chen L, Sun J, et al. Exploring the potent enhancement effects of plyometric training on vertical jumping and sprinting ability in sports individuals. *Frontiers in Physiology*, 2024;15: 1435011. https://doi.org/10.3389/fphys.2024.1435011
16. Matusiński A, Pietraszewski P, Krzysztofik M, Gołaś A. The Effects of Resisted Post-Activation Sprint Performance Enhancement in Elite Female Sprinters. *Frontiers in Physiology*, 2021;12: 651659. https://doi.org/10.3389/fphys.2021.651659
17. Pietraszewski P, Gołaś A, Zając A, Maćkała K, Krzysztofik M. The Acute Effects of Combined Isometric and Plyometric Conditioning Activities on Sprint Acceleration and Jump Performance in Elite Junior Sprinters. *Applied Sciences*, 2025;15(4): 2125. https://doi.org/10.3390/app15042125
18. Del Vecchio L, Stanton R, Reaburn P, Macgregor C, Meerkin J, Villegas J, et al. Effects of Combined Strength and Sprint Training on Lean Mass, Strength, Power, and Sprint Performance in Masters Road Cyclists. *Journal of Strength and Conditioning Research*, 2019;33(1): 66–79. https://doi.org/10.1519/JSC.0000000000001960
19. Ward C, Catháin CÓ, Chéilleachair NN, Grassick S, Kelly DT. Does Resisted Sprint Training Improve the Sprint Performance of Field-Based Invasion Team Sport Players? A Systematic Review and Meta-analysis. *Sports Medicine*, 2024;54(3): 659–672. https://doi.org/10.1007/s40279-023-01952-8
20. Bastholm M. The Role of Plyometric Training in Improving Explosive Power in Sprinters: A Qualitative Analysis. *International Journal of Sport Studies for Health*, 2024;7(3): 71–79. https://doi.org/10.61838/kman.intjssh.7.3.10
21. Shuai C, Xiangyu W, Zihao L, Xinqi J, Li G. Effects of Plyometric Training on Lower-Limb Explosive Power and Its Retention After Detraining in Sprinters. *American Journal of Men's Health*, 2025;19(4): 15579883251363089. https://doi.org/10.1177/15579883251363089
22. Zisi M, Stavridis I, Bogdanis G, Terzis G, Paradisis G. The Acute Effects of Plyometric Exercises on Sprint Performance and Kinematics. *Physiologia*, 2023;3(2): 295–304. https://doi.org/10.3390/physiologia3020021
23. Chelly MS, Hermassi S, Shephard RJ. Effects of In-Season Short-term Plyometric Training Program on Sprint and Jump Performance of Young Male Track Athletes. *Journal of Strength and*

Conditioning Research, 2015;29(8): 2128–2136. https://doi.org/10.1519/JSC.0000000000000860

24. Stojanović E, Ristić V, McMaster DT, Milanović Z. Effect of Plyometric Training on Vertical Jump Performance in Female Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine*, 2017;47(5): 975–986. https://doi.org/10.1007/s40279-016-0634-6
25. Gil S, Barroso R, Crivoi Do Carmo E, Loturco I, Kobal R, Tricoli V, et al. Effects of resisted sprint training on sprinting ability and change of direction speed in professional soccer players. *Journal of Sports Sciences*, 2018;36(17): 1923–1929. https://doi.org/10.1080/02640414.2018.1426346

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ORIGINAL ARTICLE

Dynamics of functional state recovery indicators in athletes during training camps

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Abstract

Background and Study Aim: Training camps are a stage in the annual training cycle of wrestlers. They are characterized by a high concentration of training loads and increased functional stress on the organism. Under such conditions, the effectiveness of recovery processes becomes a factor determining athletes' adaptive capacity, functional readiness, and training performance. The purpose of this study was to examine the dynamics of physiological, functional, and subjective recovery indicators in wrestlers during different stages of a training camp within the framework of medical and pedagogical monitoring.

Material and Methods: The study involved 24 male wrestlers of competitive level who participated in a centralized training camp. This was a single-group repeated-measures study with four measurement time points: baseline (3 days before the camp), initial (days 1–3), main (days 10–12), and final (days 19–21). The evaluated indicators included resting heart rate, heart rate variability parameters [root mean square of successive differences (RMSSD), primary outcome], the Ruffier index, and subjective indicators of functional state (well-being, activity, and mood). Heart rate variability was recorded under standardized resting conditions. Statistical analysis included descriptive statistics and repeated-measures ANOVA with effect sizes (partial η^2) and 95% confidence intervals for within-subject changes.

Results: The results showed a trend toward improvement in recovery-related indicators during the training camp. RMSSD increased from 50.8 ± 6.1 ms at baseline to 55.3 ± 6.9 ms at the final stage (mean change 4.5 ms; 95% CI [2.1, 6.9]; $p = 0.01$; Cohen's $dz = 0.7$). A gradual decrease in resting heart rate (from 64.1 ± 2.9 to 61.8 ± 2.6 bpm; mean change −2.3 bpm; 95% CI [−3.5, −1.1]; $p < 0.01$) and Ruffier index values was observed. These changes indicate improved cardiovascular efficiency and functional readiness. Subjective indicators of functional state also showed positive dynamics. Their progression was not strictly parallel, which indicates individual differences in the perception of training load and recovery. Despite overall favorable trends, individual analysis revealed that a subset of athletes (29.2%) exhibited less pronounced or unstable recovery dynamics.

Conclusions: The findings indicate that recovery processes during training camps are characterized by stage-dependent dynamics and inter-individual variability. The observed changes suggest improved parasympathetic modulation and cardiovascular efficiency. However, due to the single-group design, causal inferences are limited. The combined use of objective physiological indicators and subjective assessment tools provides a basis for evaluating recovery in the context of medical and pedagogical monitoring.

Keywords: functional state, recovery dynamics, training camps, heart rate variability, wrestlers; medical and pedagogical control

Glossary

Training camp — a centralized and time-limited stage of sports preparation. It is characterized by a high concentration of training loads and regulated recovery processes.

Functional state — an integrative characteristic that reflects the level of physiological readiness and adaptive capacity of an athlete.

Heart rate variability (HRV) — a non-invasive indicator of autonomic nervous system regulation. It is based on variations in time intervals between heartbeats.

Root mean square of successive differences (RMSSD) — a time-domain HRV parameter that reflects parasympathetic activity and recovery status.

Pedagogical control — a system for monitoring and managing the training process based on objective and subjective indicators of athletes' condition.

Introduction

The organization of training loads and recovery processes is a component of the preparation

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system in modern sport. Training camps are used as a concentrated stage of preparation during which athletes are exposed to increased training volume and intensity within a limited period. Such conditions create physiological and functional demands on the organism and require regulation of recovery processes. Monitoring the functional state of athletes during these periods allows tracking adaptation to training loads and changes in functional readiness.

The contemporary system of athletic training in combat sports is characterized by high training intensity, a substantial volume of specialized and competitive activities, and pronounced stress-related effects on the functional systems of athletes. In this context, the restoration of functional state is associated with performance capacity, adaptive potential, and competitive outcomes in wrestlers [1, 2]. Training camps represent a concentrated stage of the annual training cycle aimed at developing athletes' specific work capacity. The high density of training stimuli during these periods is accompanied by functional strain and may increase the risk of chronic fatigue, overtraining, and functional disturbances, particularly in highly qualified athletes [2, 3].

Wrestling involves combined manifestations of fatigue associated with high-intensity anaerobic work, strength efforts, emotional stress, and the need for rapid recovery between bouts. During training camps these factors intensify, which leads to changes in cardiovascular parameters, autonomic balance, and metabolic and neuromuscular functions [4, 5]. Such conditions require medical and pedagogical monitoring based on dynamic evaluation of athletes' functional state.

Heart rate and heart rate variability indicators are widely used for assessing functional state and recovery processes in athletes. These indicators reflect autonomic regulation and allow identification of adaptive shifts associated with training loads [6, 7, 8]. Their interpretation requires a dynamic approach and consideration of individual responses during the training camp period [9, 10]. Studies in Kazakhstani scientific literature consider restoration of functional state within the framework of medical and pedagogical monitoring systems. Static assessment of individual physiological indicators does not allow adequate evaluation of athletes' functional state without analyzing their dynamics at different stages of sports preparation under intensified training conditions [11, 12, 13].

In contemporary sports theory and practice, restoration of athletes' functional state is considered a component of training process management and medical–pedagogical monitoring. Recovery processes are viewed as a continuous part of adaptation that supports the stability of functional systems under training loads; insufficient or delayed recovery may disrupt adaptive mechanisms and reduce training effectiveness [1]. International studies indicate that monitoring recovery helps prevent overtraining syndrome and chronic fatigue. Early signs of functional overstrain may remain undetected when isolated assessments are used, which supports the need for systematic monitoring of athletes' functional state [9].

Training camps represent a form of training organization characterized by a high concentration of training stimuli and limited opportunities for spontaneous recovery. During these periods, a mismatch between training loads and recovery capacities may occur, particularly in highly qualified athletes [2]. Inadequate recovery under such conditions may reduce work capacity and lead to unfavorable adaptive responses [3, 14, 15].

Heart rate and heart rate variability (HRV) indicators are widely used for assessing functional state and recovery processes. HRV reflects autonomic regulation and allows identification of adaptive shifts associated with training stimuli [6]. The RMSSD index reflects parasympathetic activity and is used for monitoring recovery under training camp conditions; its decrease is associated with increased training stress, whereas its increase indicates recovery processes [7, 8, 16, 17]. Ultra-short HRV recordings have also been proposed for rapid monitoring of athletes' functional state during training camps [7, 16, 17]. These approaches are also considered applicable in combat sports, where monitoring of functional state is required under conditions of high training loads and mixed physical demands [18].

Contemporary monitoring approaches emphasize comprehensive assessment of recovery that combines physiological, functional, and subjective indicators. Integrating objective data with subjective recovery and well-being scales improves interpretation of adaptive responses and detection of insufficient recovery [19]. Such monitoring supports adjustment of training content, volume, and intensity according to athletes' functional state and increases the diagnostic value of monitoring under training camp conditions [8, 15].

Wrestling is characterized by high-intensity motor activity, a substantial share of anaerobic work, and psycho-emotional stress. Wrestlers demonstrate metabolic, autonomic, and neuromuscular manifestations of fatigue [4]. Intensive training cycles are associated with changes in hormonal status, markers of muscle damage, and autonomic regulation, while adaptive responses depend on the structure of training loads and the conditions of their implementation [5, 18, 19, 20].

Analysis of research findings has shown that monitoring the restoration of athletes' functional state is considered an element of training process management and medical–pedagogical monitoring. Researchers emphasize that indicators of heart rate

and heart rate variability, including RMSSD, allow the identification of adaptive responses associated with training loads and recovery processes during periods of intensified preparation. Authors also note that effective monitoring requires dynamic assessment of physiological and subjective indicators throughout the training cycle, particularly under conditions of concentrated training loads such as training camps. At the same time, interpretation of recovery indicators during different stages of training camps remains a complex task due to variability in athletes' responses and the interaction of physiological and training-related factors.

Additionally, scientific evidence indicates that restoration of functional state is associated with the effectiveness of the training process during training camps. Existing studies often focus on individual indicators or examine other sports and stages of the annual training cycle. As a result, the dynamics of recovery indicators during different stages of training camps and the variability of athletes' responses are not always considered in an integrated manner. In the context of physical culture and sport pedagogy, recovery indicators are used not only as physiological characteristics but also as elements of pedagogical diagnostics that support regulation of training loads and feedback within the training process. These circumstances indicate the relevance of further examination of the dynamics of recovery indicators during the training camp period within the framework of systematic monitoring of athletes' functional state.

To examine the dynamics of physiological, functional, and subjective recovery indicators in wrestlers during different stages of a training camp within the framework of medical and pedagogical monitoring. It was assumed that recovery indicators of functional state in wrestlers during a training camp would demonstrate stage-dependent and individual variability associated with adaptation to training loads and recovery processes. It was also assumed that dynamic monitoring of physiological, functional, and subjective indicators would allow identification of changes in athletes' functional state at different stages of the training camp.

Materials and Methods

Participants

The study involved male wrestlers (n = 24) specializing in Greco-Roman and freestyle wrestling, aged 18–24 years. The athletes' qualification levels corresponded to Candidate for Master of Sport (advanced-level athletes) and Master of Sport (highly qualified athletes) of the Republic of Kazakhstan. All participants had at least six years of systematic training experience. They had no acute or exacerbated chronic diseases and were cleared for training loads based on the results of comprehensive medical examinations. The athletes had a body mass of 70.3 ± 8.5 kg, a height of 174.2 ± 6.8 cm, and training experience of 7.8 ± 1.9 years. Participation in the study was voluntary and conducted in accordance with ethical standards for scientific research in sport.

Exclusion criteria were injury during the camp, use of medications affecting autonomic function (e.g., beta-blockers), and failure to complete all four measurements. A post hoc power analysis (G*Power 3.1) indicated that with 24 participants and a moderate effect size (f = 0.25) for the repeated-measures factor, the study had 80% power to detect a significant time effect at $\alpha = 0.05$.

Research Design

This was a prospective single-group repeated-measures study. Due to the absence of a comparator group, the analysis was limited to within-subject temporal associations and does not allow causal conclusions. The study was conducted during scheduled training camps involving athletes specializing in wrestling in the preparatory period of the annual training cycle. The duration of the training camp was 21 days, which corresponds to methodological recommendations for organizing the training process in combat sports. The study was conducted using a repeated-measures framework.

Four assessment stages were identified:

- baseline stage — 3 days prior to the start of the training camp;
- initial stage — days 1–3 of the training camp;
- main stage — days 10–12;
- final stage — days 19–21 of the training camp.

All assessments were conducted at the same time of day, in the morning hours prior to the start of training sessions and under conditions of relative rest. This approach minimized the influence of circadian variations in functional indicators.

A comprehensive assessment of wrestlers' functional state recovery was performed using physiological, functional, and subjective methods. Heart rate variability measurements were recorded in a standardized body position.

The 21-day training camp consisted of two training sessions per day (morning and afternoon), six days per week. Each session lasted 90–120 minutes. The training content included technical–tactical drills (60% of total time), strength and conditioning exercises (30%), and recovery activities (10%). Intensity was monitored using heart rate (Polar H10) and session rating of perceived exertion (sRPE, CR-10 scale). The mean weekly training volume was approximately 18 hours, with an average intensity of 75–85% of individual maximal heart rate during the main sessions.

The primary outcome was RMSSD (root mean square of successive differences), a time-domain heart rate variability index reflecting

parasympathetic activity. Secondary outcomes included resting heart rate (HRrest), SDNN (standard deviation of NN intervals), the Ruffier index, and subjective ratings of well-being, activity, and mood.

Heart rate variability (HRV) recording. All measurements were performed in the morning (07:00–08:00) after an overnight fast. Athletes were in a supine position following 10 minutes of quiet rest. A 5-minute RR interval recording was obtained using a Polar H10 chest strap (Polar Electro, Finland) with a sampling rate of 1000 Hz. Data were transferred to Kubios HRV Standard software (version 3.5) for analysis. Artifact correction was performed using the automatic filter (medium level) and was manually verified. The within-subject coefficient of variation for RMSSD in our laboratory is <5% (based on test–retest reliability in 10 athletes). This value is consistent with reliability estimates for short-term HRV recordings reported in previous studies [16].

Ruffier test. Athletes performed 30 squats in 45 seconds. Heart rate was measured at rest (P0), immediately after exercise (P1), and after one minute of recovery (P2). The Ruffier index was calculated as (P0 + P1 + P2 − 200) / 10.

Subjective assessments. Athletes completed a modified version of the Well-Being, Activity, and Mood questionnaire (Russian adaptation of the SAN scale) before HRV measurements during the training camp stages (initial, main, and final). Each item was rated on a 5-point Likert scale (1 = very low, 5 = very high).

Statistical Analysis

Statistical analyses were performed using SPSS Statistics 26.0 (IBM, USA). Data are presented as mean ± standard deviation (M ± SD). Normality of distribution was tested using the Shapiro–Wilk test. All variables met the normality assumption ($p > 0.05$), except for subjective scores, which were analyzed using non-parametric tests.

A one-way repeated-measures ANOVA was conducted with Time (baseline, initial, main, final) as the within-subject factor. Mauchly's test of sphericity was applied, and if the assumption was violated, the Greenhouse–Geisser correction was used. Effect sizes are reported as partial eta-squared (η^2) with 90% confidence intervals.

For the primary outcome (RMSSD) and other continuous variables, pairwise comparisons between the baseline and final stages were performed using paired t-tests. Mean differences, 95% confidence intervals (CI), and Cohen's dz effect size were calculated. For subjective indicators (ordinal data), the Friedman test was used, followed by Wilcoxon signed-rank tests with Bonferroni correction for post hoc comparisons.

There were no missing data; all 24 participants completed all four assessments. Statistical significance was set at $\alpha = 0.05$ (two-tailed). No adjustment for multiple comparisons was applied to the primary contrast because it was prespecified a priori (baseline vs. final RMSSD). Analyses of secondary outcomes and additional pairwise comparisons were considered exploratory and interpreted accordingly.

Results

All 24 participants completed measurements at all four time points (baseline, initial, main, and final), and no data were missing. Descriptive characteristics of physiological and functional indicators across the training camp stages are presented in Table 1.

As shown in Table 1, repeated-measures ANOVA revealed significant time effects for all cardiovascular indicators. Resting heart rate increased during the initial stage compared with baseline ($p < 0.001$) and then gradually decreased during the subsequent stages, reaching values below baseline by the final stage ($p < 0.01$). Heart rate variability indicators also showed significant

Table 1. Dynamics of physiological and functional indicators during the training camp (M ± SD) with repeated-measures ANOVA and effect sizes.

Indicator	Baseline	Initial	Main	Final	Time effect (RM-ANOVA)	Baseline–Final change
Resting HR, bpm	64.1 ± 2.9	68.5 ± 3.2	66.4 ± 3.1	61.8 ± 2.6	$F(2.1,48.3)=12.4$, $p<0.001$, $\eta^2=0.35$	Δ = −2.3 bpm; 95% CI [−3.5, −1.1]; Cohen's dz = 0.8
RMSSD, ms	50.8 ± 6.1	42.1 ± 6.4	45.0 ± 7.2	55.3 ± 6.9	$F(2.3,52.9)=8.9$, $p<0.001$, $\eta^2=0.28$	Δ = +4.5 ms; 95% CI [2.1, 6.9]; Cohen's dz = 0.7
SDNN, ms	88.6 ± 8.4	78.4 ± 9.2	81.2 ± 9.0	93.7 ± 9.5	$F(2.2,50.6)=7.6$, $p=0.001$, $\eta^2=0.25$	Δ = +5.1 ms; 95% CI [2.3, 7.9]; Cohen's dz = 0.6
Ruffier index, a.u.	7.4 ± 1.0	9.8 ± 1.1	8.7 ± 1.0	6.9 ± 0.9	$F(2.4,55.2)=9.8$, $p<0.001$, $\eta^2=0.30$	Δ = −0.5; 95% CI [−1.0, 0.0]; Cohen's dz = 0.4

Notes: Data are presented as mean ± SD. The time effect was assessed using one-way repeated-measures ANOVA. The Greenhouse–Geisser correction was applied when the sphericity assumption was violated. The effect size for ANOVA is reported as partial η^2. The baseline–final change is presented as the mean difference (Δ) with a 95% confidence interval and Cohen's dz. For the Ruffier index, the baseline–final comparison did not reach statistical significance.

temporal changes. RMSSD decreased during the initial stage ($p < 0.001$), partially recovered during the main stage, and exceeded baseline values by the final stage ($p = 0.01$). SDNN demonstrated a similar pattern of change. The Ruffier index increased during the initial stage compared with baseline ($p < 0.001$), decreased during the main stage, and returned to baseline levels by the final stage.

Subjective well-being, activity, and mood scores decreased during the initial stage compared with baseline (all $p < 0.01$). In the main stage, these indicators improved for the group, although individual variability remained. By the final stage, subjective scores increased further and variability decreased (Table 2).

As shown in Table 2, individual analysis revealed that 7 athletes (29.2%) did not demonstrate an increase in RMSSD from the initial to the main stage, and their values remained below baseline during this period. These athletes also reported lower subjective well-being scores in the main stage compared with the rest of the group ($p = 0.008$). Comparative analysis indicated inter-individual variability in recovery responses. Athletes with higher baseline RMSSD values showed greater recovery by the final stage compared with athletes with lower baseline RMSSD ($p = 0.02$). In addition, athletes with delayed HRV recovery demonstrated higher resting heart rate at the final stage than the rest of the group ($p = 0.01$). Table 2 presents the dynamics of subjective recovery indicators assessed during the training camp.

Resting heart rate showed a significant decreasing trend from the initial to the final stage ($F(2.1, 48.3) = 12.4$, $p < 0.001$, $\eta^2 = 0.35$; Figure 1). Individual trajectories varied, as indicated by the standard deviation bars.

RMSSD dynamics (Figure 2) showed a significant quadratic trend ($F(1, 23) = 14.2$, $p < 0.001$, $\eta^2 = 0.38$), with an initial decrease followed by an increase above baseline. The 95% confidence intervals for mean RMSSD at each time point are shown in Figure 2.

The Ruffier index (Figure 3) showed a significant overall time effect ($F(2.4, 55.2) = 9.8$, $p < 0.001$, $\eta^2 = 0.30$). Pairwise comparisons confirmed significant differences between the initial and final stages ($p < 0.001$). However, the baseline–final comparison did not reach statistical significance ($p = 0.06$).

Subjective indicators (Figure 4) showed significant changes over time (Friedman $\chi^2 > 12$, $p < 0.01$ for all measures). Post hoc comparisons

Table 2. Dynamics of subjective indicators of functional state during the training camp.

Indicator	Initial stage	Main stage	Final stage	χ^2 (df=2)	p-value
Well-being	3 [3–4]	4 [3–4]	4 [4–5]	14.2	<0.001
Activity	3 [3–4]	4 [3–4]	4 [4–5]	12.8	0.002
Mood	3 [3–4]	4 [4–4]	5 [4–5]	16.5	<0.001

Note: Data are presented as median [IQR]. Changes over time were assessed using the Friedman test. χ^2 is the Friedman test statistic; df = 2; n = 24.

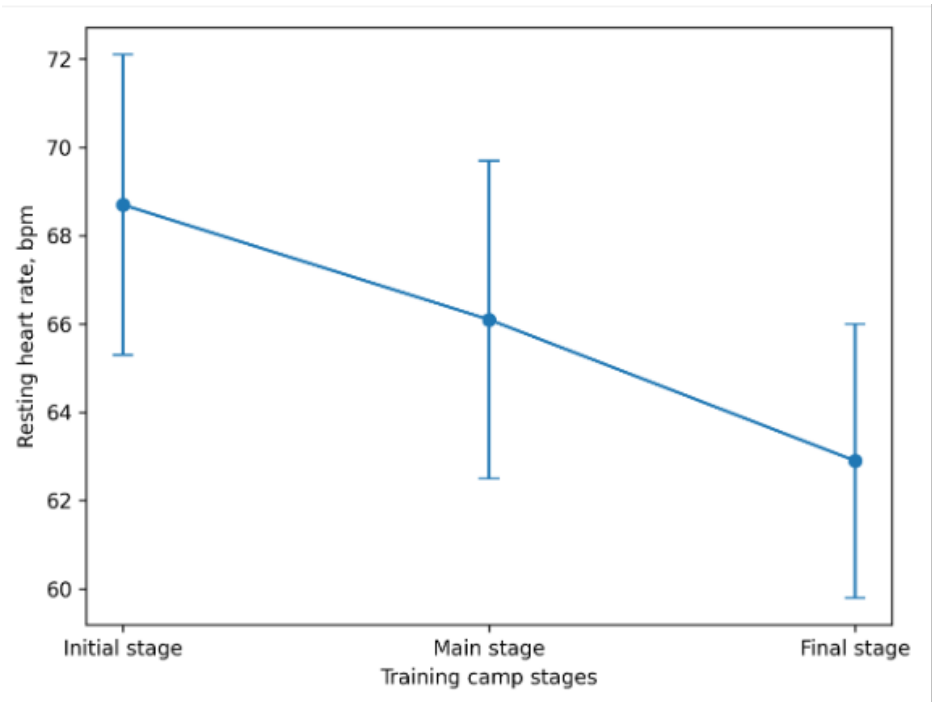

Figure 1. Dynamics of resting heart rate during the training camp (mean ± SD).

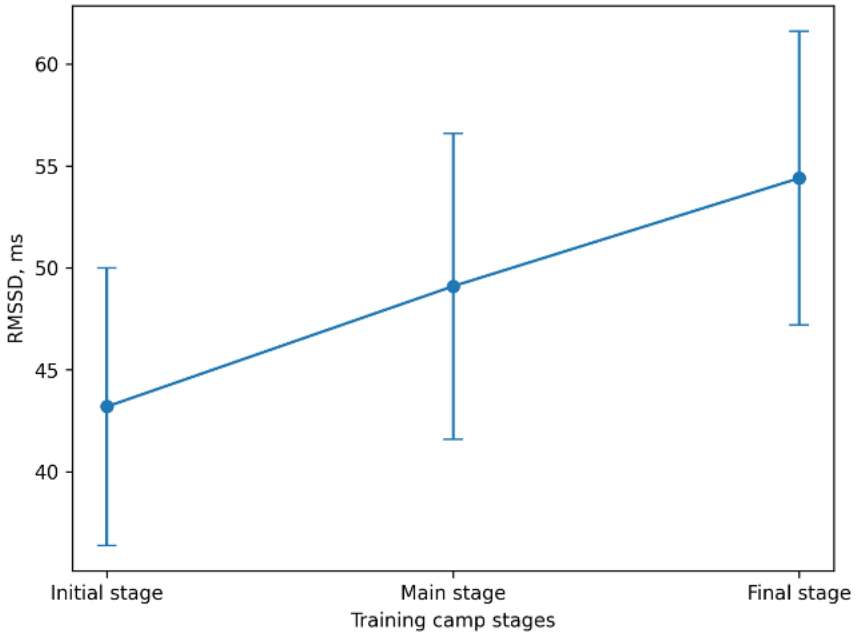

Figure 2. Dynamics of RMSSD during the training camp (mean ± SD).

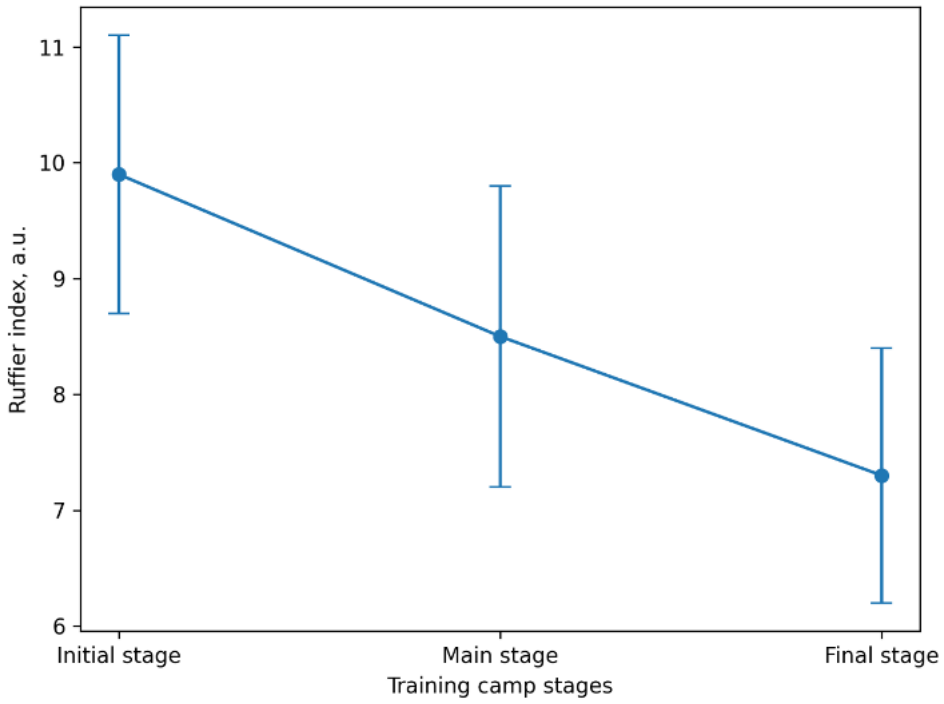

Figure 3. Dynamics of the Ruffier index during the training camp (mean ± SD).

indicated that final scores were higher than initial scores for all three measures ($p < 0.01$).

Subjective indicators (Figure 4) showed significant changes over time (Friedman $\chi^2 > 12$, $p < 0.01$ for all measures). Post hoc comparisons indicated that final scores were higher than initial scores for all three measures ($p < 0.01$).

Individual analysis revealed that 7 athletes (29.2%) exhibited atypical responses: their RMSSD did not exceed baseline values by the final stage (48.2 ± 4.1 ms vs. baseline 50.5 ± 5.2 ms, $p = 0.28$), and their resting heart rate remained higher than in the rest of the group (64.5 ± 2.8 vs. 60.8 ± 2.1 bpm, $p = 0.01$).

Discussion

The purpose of this study was to examine the dynamics of physiological, functional, and subjective recovery indicators in wrestlers during different stages of a training camp within the framework of medical and pedagogical monitoring. The findings show that training camps represent a period of pronounced functional strain that requires systematic monitoring of recovery processes. The

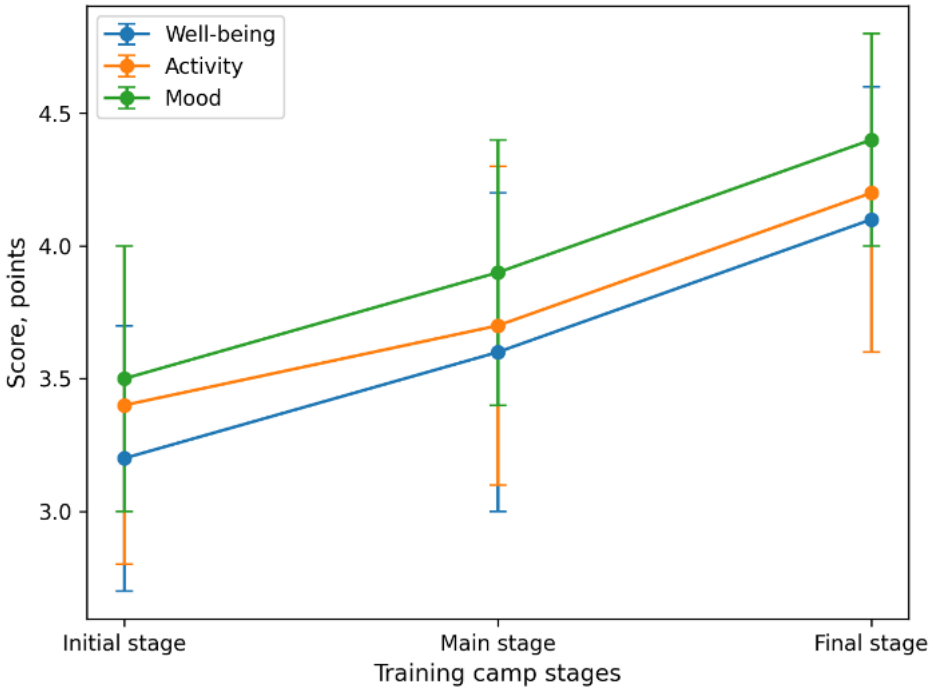

Figure 4. Dynamics of subjective functional state indicators during the training camp (mean ± SD).

observed decrease in resting heart rate and the increase in heart rate variability indices in the majority of wrestlers suggest the development of adaptive shifts consistent with improved cardiovascular efficiency and parasympathetic regulation. These results are consistent with contemporary concepts of the physiological mechanisms underlying athlete recovery [6, 7, 8].

An increase in the RMSSD index during training camps is regarded by several authors as an indicator of an adequate balance between training load and recovery interventions [6, 14]. Studies conducted under training camp conditions have shown that positive RMSSD dynamics are associated with increased adaptive reserve and a reduced risk of accumulated fatigue [8, 13]. The results of the present study are generally consistent with the findings of Chen Y.-S. et al. and Coelho A. B. et al., who confirmed the diagnostic value of heart rate variability indicators for monitoring recovery under conditions of centralized training [7, 8].

At the same time, the individual differences identified in the dynamics of recovery indicators in 29.2% of wrestlers indicate that the positive group trend is not universal. Similar evidence has been reported in studies highlighting pronounced individual variability in autonomic regulation responses to training loads, particularly in sports characterized by high intensity and psycho-emotional stress [5, 16]. In wrestling, such variability may be associated with differences in training experience, functional readiness, bout style, as well as individual sensitivity to training loads and recovery interventions.

From a pedagogical perspective, the identified individual differences in recovery dynamics support the transition from standardized approaches to more individualized regulation of training loads. The use of dynamic recovery data enables coaches to adjust training tasks and maintain a balance between training load and recovery.

From the standpoint of medical–pedagogical monitoring, the present findings confirm the limitations of static assessments of athletes' functional state. Single-point measurements of heart rate or HRV do not allow detection of latent signs of inadequate recovery, whereas dynamic monitoring during the training camp provides a more objective assessment of adaptive processes and enables timely adjustment of training loads [9, 10].

The results of the study are consistent with the research hypothesis and demonstrate the feasibility of using dynamic monitoring of functional state recovery indicators under training camp conditions. They emphasize the necessity of individualizing medical–pedagogical monitoring in wrestling, while acknowledging that causal interpretations require controlled designs.

Limitations of the study

Several limitations of the present study should be acknowledged. First, the single-group design without a control group precludes causal attribution of the observed changes to the training camp itself. Second, the sample size (n = 24) was not based on an a priori power calculation, which may affect the generalizability of the findings. Third, the absence of biochemical markers of fatigue and the limited

range of subjective recovery indicators restrict deeper mechanistic insights. Future studies should include a control group and objective markers of stress and recovery and should employ controlled designs to confirm causality and explore underlying mechanisms. These limitations do not diminish the significance of the obtained results; they define directions for future research aimed at expanding the set of diagnostic criteria and conducting a more in-depth analysis of individual recovery trajectories in wrestlers.

Conclusions

1. Over the course of the training camp, the majority of athletes showed a progressive increase in RMSSD (mean change +4.5 ms; 95% CI [2.1, 6.9]) and a decrease in resting heart rate (mean change −2.3 bpm; 95% CI [−3.5, −1.1]), suggesting improved parasympathetic modulation and cardiovascular efficiency.
2. However, 29.2% of athletes exhibited less pronounced or unstable recovery dynamics, indicating inter-individual variability in adaptive responses.
3. Dynamic monitoring of physiological (HRV, heart rate), functional (Ruffier index), and subjective indicators provided a comprehensive picture of recovery processes and allowed early identification of athletes with potential incomplete recovery.

These findings support the inclusion of repeated-measures monitoring in medical–pedagogical practice to individualize training load management. Due to the absence of a control group, the observed changes cannot be causally attributed to the training camp itself and represent temporal associations.

The practical significance of the study lies in the proposed set of indicators that can be integrated into routine monitoring of wrestlers during training camps to enhance the quality of training process management and help prevent chronic fatigue and overtraining.

Conflict of Interest

The authors declare no conflict of interest.

Use of artificial intelligence tools

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to improve language clarity and academic style. The authors reviewed and edited the content and take full responsibility for the final version of the manuscript.

References

1. Platonov VN. *System of athletes' preparation in Olympic sport: General theory and its practical applications*. Kyiv: Olympic Literature; 2015.
2. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, 2014;44(S2):139–147. https://doi.org/10.1007/s40279-014-0253-z
3. Badea D. The Recovery of the Effort Capacity during Training Camps. In: *5th International Congress of Physical Education, Sports and Kinetotherapy,* 2016. P. 128–135. https://doi.org/10.15405/epsbs.2016.06.18
4. Franchini E, Brito CJ, Artioli GG. Weight loss in combat sports: physiological, psychological and performance effects. *Journal of the International Society of Sports Nutrition*, 2012;9(1): 52. https://doi.org/10.1186/1550-2783-9-52
5. Karaman ME, Arslan C, Kinaci AE. The Effect of Single Bout of Competitive Training on Muscle Damage and Liver Enzymes in University Student Wrestling and Taekwondo Athletes. *Journal of Pharmaceutical Research International*, 2021; 26–30. https://doi.org/10.9734/jpri/2021/v33i1731304
6. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? *Frontiers in Physiology*, 2014;5. https://doi.org/10.3389/fphys.2014.00073
7. Chen YS, Clemente FM, Bezerra P, Lu YX. Ultra-Short-Term and Short-Term Heart Rate Variability Recording during Training Camps and an International Tournament in U-20 National Futsal Players. *International Journal of Environmental Research and Public Health*, 2020;17(3): 775. https://doi.org/10.3390/ijerph17030775
8. Coelho A, Nakamura F, Morgado M, Holmes C, Di Baldassarre A, Esco M, et al. Heart Rate Variability and Stress Recovery Responses during a Training Camp in Elite Young Canoe Sprint Athletes. *Sports*, 2019;7(5): 126. https://doi.org/10.3390/sports7050126
9. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM). *European Journal of Sport Science*, 2013;13(1): 1–24. https://doi.org/10.1080/17461391.2012.730061
10. Sylta Ø, Tønnessen E, Seiler S. From Heart-Rate Data to Training Quantification: A Comparison of 3 Methods of Training-Intensity Analysis. *International Journal of Sports Physiology and Performance*, 2014;9(1): 100–107. https://doi.org/10.1123/ijspp.2013-0298
11. Kulanbaev AB, Mustafin AS, Sagyndykov AK. Funktsional'noe sostoyanie sportsmenov v sisteme vrachebno-pedagogicheskogo kontrolya [Functional state of athletes in the system of medical and pedagogical control]. *Theory and Methodology of Physical Culture,* 2018;3:45-52. (In Russian).
12. Sagyndykov AK. *Mediko-biologicheskie osnovy uprleniya trenirovochnym protsessom sportsmenov* [Medical and biological foundations of managing the training process of athletes]. Almaty; 2020. (In Russian).

13. Nurgaliev AT, Zhumabekov NK. Variabel'nost' serdechnogo ritma kak pokazatel' vosstanovleniya sportsmenov [Heart rate variability as an indicator of athletes' recovery]. *Bulletin of the Academy of Sports and Tourism,* 2022;3:45-52. (In Russian).
14. Clemente FM, Silva AF, Sarmento H, Ramirez-Campillo R, Chiu YW, Lu YX, et al. Psychobiological Changes during National Futsal Team Training Camps and Their Relationship with Training Load. *International Journal of Environmental Research and Public Health*, 2020;17(6): 1843. https://doi.org/10.3390/ijerph17061843
15. Chen YS, Pagaduan JC, Bezerra P, Crowley-McHattan ZJ, Kuo CD, Clemente FM. Agreement of Ultra-Short-Term Heart Rate Variability Recordings DuringOverseasTrainingCampsinUnder-20National Futsal Players. *Frontiers in Psychology*, 2021;12: 621399. https://doi.org/10.3389/fpsyg.2021.621399
16. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training Adaptation and Heart Rate Variability in Elite Endurance Athletes: Opening the Door to Effective Monitoring. *Sports Medicine*, 2013;43(9): 773–781. https://doi.org/10.1007/s40279-013-0071-8
17. Kellmann M, Bertollo M, Bosquet L, Brink M, Coutts AJ, Duffield R, et al. Recovery and Performance in Sport: Consensus Statement. *International Journal of Sports Physiology and Performance*, 2018;13(2): 240–245. https://doi.org/10.1123/ijspp.2017-0759
18. Chernozub A, Korobeynikov G, Mytskan B, Korobeinikova L, Cynarski WJ. Modelling Mixed Martial Arts Power Training Needs Depending on the Predominance of the Strike or Wrestling Fighting Style. *Ido Movement for Culture. Journal of Martial Arts Anthropology*, 2018;(18): 28–36. https://doi.org/10.14589/ido.18.3.5
19. Bahenský P, Grosicki GJ. Superior Adaptations in Adolescent Runners Using Heart Rate Variability (HRV)-Guided Training at Altitude. *Biosensors*, 2021;11(3): 77. https://doi.org/10.3390/bios11030077
20. Nagovitsyn RS, Volkov PB, Miroshnichenko AA, Tutolmin AA, Senator SYu. The influence of special graduated weight load in Greco-Roman wrestling on the growth of students' sports results. *Physical Education of Students*, 2017;21(6): 294. https://doi.org/10.15561/20755279.2017.0606

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ORIGINAL ARTICLE

Qualification-related differences in ankle kinematics during the right-hand uppercut in competitive boxers

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Abstract

Background and Study Aim: Punching performance in boxing depends on coordinated kinetic chain interactions between the lower and upper limbs. During the execution of the uppercut, the ankle joint contributes to body stabilization and force transfer across movement phases. Although various biomechanical parameters are used to analyze punching technique, the influence of qualification level on ankle joint kinematics during the uppercut remains a subject of practical interest. This study aimed to examine how qualification level influences ankle kinematics during the right-hand uppercut in male boxers of high sport qualification.

Material and Methods: A total of 36 male boxers were stratified into two qualification groups: Masters of Sport (highly qualified boxers) (n = 18) and Candidate Masters of Sport (advanced-level boxers) (n = 18). Participants performed maximal-effort right-hand uppercuts under controlled laboratory conditions. Ankle joint kinematics were assessed using three-dimensional motion analysis (3DMA). The analysis included minimum and maximum joint angles, range of motion (ROM), maximum angular velocity, toe-off angle, mid-support angle, and propulsion distance. Between-group differences were evaluated using bias-corrected Hedges' g with 95% confidence intervals (CI). Effect magnitude and η^2 were calculated to estimate the practical relevance of the results.

Results: The most significant standardized difference was observed in the right ankle mid-support angle (g = 0.76, 95% CI 0.08 to 1.44; η^2 = 0.14). It was followed by the right ankle minimum angle (g = 0.72, 95% CI 0.04 to 1.40; η^2 = 0.13). Moderate effects were found in the left ankle ROM (g = 0.67, 95% CI -0.00 to 1.34; η^2 = 0.11). Moderate but statistically uncertain effects were observed in the right ankle maximum angle and toe-off angle (g = 0.55; CIs crossing zero). In contrast, maximum angular velocity and propulsion distance demonstrated small standardized differences (g = 0.30–0.40), with confidence intervals overlapping the null value.

Conclusions: Qualification level is primarily associated with differences in ankle joint positioning and stabilization during transitional support phases rather than with peak angular velocity output. The findings suggest that advanced technical proficiency in boxing may be characterized by refined sagittal-plane control and phase-specific joint modulation. Further studies integrating kinetic measurements and larger sample sizes are needed to confirm these biomechanical tendencies.

Keywords: boxing biomechanics, ankle joint, uppercut, effect size analysis, sagittal-plane kinematics, combat sports.

Introduction

In boxing, effective punching actions emerge from coordinated interactions across multiple segments of the kinetic chain. The generation and transfer of force during punching movements depend on the synchronized contribution of the lower limbs, trunk, and upper extremities. Within this sequence, the ankle joint contributes to postural stabilization and mechanical support during transitional phases of movement. Variations in joint positioning and movement patterns may influence how force is transmitted through the body during the execution of specific punching techniques.

Punching performance in boxing represents a high-velocity, multi-segment motor action requiring coordinated intersegmental sequencing of the lower and upper extremities. Effective force transmission from the ground to the striking fist

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depends on precise temporal coordination, joint positioning, and segmental acceleration within the kinetic chain framework [1, 2]. Earlier biomechanical analyses of punching mechanics demonstrated that effective mass transfer and impulse generation are determinants of strike performance [1, 3].

Advances in three-dimensional motion analysis have expanded understanding of punching biomechanics over the past decade. Kinematic and kinetic investigations have demonstrated that trunk rotation, coordinated segmental motion, and temporal sequencing of body segments contribute to effective force generation during punching actions [4, 5]. Subsequent biomechanical analyses have also identified distinct movement phases and emphasized the role of intersegmental coordination in the execution of various punch types, including the cross, hook, and uppercut [2, 6]. In addition, kinematic comparisons of single and combination punches indicate that punch execution involves coordinated segmental velocity patterns across the kinetic chain [7]. Comparative investigations across competitive levels further show that elite boxers demonstrate more refined temporal coordination and proximal-to-distal sequencing patterns than junior athletes [6, 8].

Lower-extremity mechanics are recognized as important contributors to punching performance. Interactions between the hip, knee, and ankle joints influence ground reaction force development, propulsion, and stabilization during punching movements [9, 10, 11, 12]. Studies examining strength–power characteristics and force-development indices have demonstrated associations between lower-limb mechanical output and punch impact magnitude in trained boxers [9, 11, 13]. In addition, recent investigations using wearable sensors, inertial measurement units, and machine-learning-based kinematic analysis have further highlighted the contribution of coordinated lower-limb mechanics to high-velocity striking movements in combat sports [14, 15, 16].

Much of the biomechanical research on punching has examined trunk rotation, segmental coordination, and the temporal sequencing of body segments during striking actions [2, 5, 10]. The uppercut differs mechanically from linear punches because it involves greater vertical movement components and dynamic transitions between support phases during strike execution [6, 17]. These characteristics suggest that lower-limb stabilization and push-off coordination may contribute to the organization of the kinetic chain and may influence proximal segment acceleration.

The ankle joint contributes to load absorption, propulsion, and postural stabilization during dynamic movements in combat sports [18, 19]. Biomechanical investigations of striking and rotational tasks indicate that variations in distal joint positioning may influence the transmission of motion through the kinetic chain [18, 20, 21]. Electromyographic studies of punching movements demonstrate coordinated activation of lower- and upper-limb musculature during strike execution [22], supporting the concept of integrated segmental control within the kinetic chain. Previous investigations have also reported differences in punch force production and coordination between athletes of different competitive levels [6, 23]. However, the specific contribution of ankle joint angular characteristics across qualification levels remains insufficiently examined. Recent developments in instrumented striking systems and biomechanical modeling provide additional methodological possibilities for joint-level analysis of punching movements [24, 25, 26].

Analysis of research findings has shown that punching performance in boxing depends on coordinated interactions among multiple segments of the kinetic chain, including contributions from the lower extremities, trunk, and upper limbs. Researchers emphasize that temporal sequencing of segmental movements, joint positioning, and force transmission patterns influence the mechanical effectiveness of striking actions. At the same time, biomechanical characteristics of different punching techniques involve specific movement demands and support-phase transitions that affect distal joint function and stabilization strategies. These factors indicate the relevance of examining ankle joint kinematics during the execution of complex punching actions in boxing. Despite these findings, qualification-dependent variation in ankle kinematics during uppercut execution remains insufficiently examined. Analysis of whether qualification status is associated with systematic differences in ankle joint positioning and angular velocity may provide insight into phase-specific motor control strategies and technical refinement mechanisms in high-level boxing performance.

Therefore, the present exploratory pilot study aimed to examine qualification-dependent differences in sagittal-plane ankle joint kinematic parameters during execution of the right-hand uppercut in boxers of high sport qualification. In accordance with this objective, it was hypothesized that boxers of higher qualification would demonstrate differences in sagittal-plane ankle joint positioning and range-of-motion characteristics during transitional support phases of the uppercut compared with boxers of lower qualification. It was also assumed that qualification level may be associated with differences in ankle angular velocity parameters during punch execution.

Materials and Methods

Participants

A total of 36 male boxers participated in this

cross-sectional laboratory study and were stratified according to sport qualification into two groups: highly qualified boxers (n = 18) and advanced-level boxers (n = 18). Participants in both groups demonstrated comparable anthropometric characteristics. The highly qualified group had a mean age of 21.0 ± 1.2 years, mean body height of 176.0 ± 3.0 cm, and mean body mass of 60.0 ± 2.1 kg, whereas the advanced-level group presented similar age and stature (21.0 ± 1.4 years, 176.0 ± 2.8 cm) with slightly higher body mass (62.5 ± 3.5 kg).

Inclusion criteria required athletes to have a minimum of five years of structured boxing training and to be actively competing at the national level at the time of testing. Exclusion criteria included any lower-extremity musculoskeletal injury or other performance-limiting condition within the six months preceding data collection.

All procedures complied with the Declaration of Helsinki and were approved by the Ethics Committee of the Uzbek State University of Physical Education and Sport (Approval No. 15/AT2.10/2025). Written informed consent was obtained from all participants prior to participation.

Research Design

This investigation was designed as an exploratory cross-sectional pilot study aimed at identifying preliminary biomechanical tendencies in ankle joint kinematics associated with athlete qualification level. Due to the limited availability of high-level combat sport athletes and strict inclusion criteria, the study was not intended to provide causal conclusions but rather to generate hypothesis-generating insights to inform future larger-scale investigations.

Independent comparisons were performed to assess baseline anthropometric characteristics between groups. No statistically significant differences were observed ($p > 0.05$), indicating comparable baseline characteristics between the groups. A post-hoc power analysis was conducted to estimate the statistical power of the sample size. With 18 participants per group ($\alpha = 0.05$), the sample provided approximately 80% statistical power to detect large effect sizes (Hedges' $g \geqslant 0.90$).

Participants performed a standardized boxing-specific warm-up before testing. Each athlete executed several maximal-effort right-hand uppercuts toward a fixed target under controlled laboratory conditions. To ensure technical consistency, a certified boxing coach supervised all trials and verified correct movement execution. Given the exploratory design and the high technical consistency expected among high-level athletes, the single best technically valid trial was selected for biomechanical analysis. A trial was considered technically valid if the punch was executed with a proper uppercut trajectory and without marker occlusion. This approach was adopted to minimize variability associated with submaximal or technically inconsistent attempts. Uppercut execution was temporally divided into three biomechanical phases:

1. Preparation phase
2. Mid-support phase
3. Propulsion phase.

Phase boundaries were identified using kinematic event detection based on ankle and pelvis marker trajectories.

Instrumentation

Three-dimensional kinematic data were collected at the Sports Biomechanics Laboratory, Scientific Research Center, Uzbek State University of Physical Education and Sport, Chirchik, Uzbekistan, using the STT Systems 3D Motion Analysis platform (3DMA 2023.0, Motive software; STT Systems, San Sebastián, Spain).

The motion capture system consisted of a multi-camera infrared optoelectronic setup operating at a sampling frequency of 120 Hz, enabling full-body three-dimensional reconstruction of segmental motion during dynamic athletic movements.

Segment coordinate systems were defined according to the International Society of Biomechanics (ISB) recommendations [27, 28].

Data acquisition and processing were performed using STT Motive 3DMA software (Version 2023.0). The recording protocol followed the Full-Body 19-Point Helen Hayes biomechanical model, allowing three-dimensional reconstruction of the trunk, pelvis, neck, shoulders, elbows, hips, knees, and ankles.

Reflective markers (14 mm diameter) were placed bilaterally on standardized anatomical landmarks according to a modified Helen Hayes lower-extremity configuration, including:

- greater trochanter
- lateral femoral epicondyle
- tibial tuberosity
- medial and lateral malleoli
- calcaneus
- second metatarsal head.

The STT 3D Motion Analysis system enables computation of:

- three-dimensional joint angles (sagittal, frontal, and transverse planes)
- phase-specific angular parameters (contact, mid-support, toe-off)
- maximum angular velocity (°/s)
- spatiotemporal displacement variables (mm)
- center-of-mass oscillation
- propulsion and braking distance
- time-normalized kinematic curves.

Angular velocity was calculated as the first derivative of angular displacement with respect to time.

Although full three-dimensional kinematics were recorded, the present analysis focused on sagittal-plane ankle mechanics, reflecting

the plantarflexion-dominant propulsion and predominantly vertical force-vector orientation characteristic of the uppercut technique.

The following ankle-specific variables were extracted:

- minimum dorsiflexion angle (°)
- maximum plantarflexion angle (°)
- range of motion (ROM, °)
- maximum angular velocity (°/s)
- toe-off angle (°)
- mid-support angle (°)
- propulsion displacement (mm).

Raw marker trajectories were filtered using a fourth-order zero-lag low-pass Butterworth filter with a cut-off frequency between 6 and 10 Hz, determined via residual analysis to minimize signal noise while preserving movement dynamics.

All punch cycles were time-normalized to 100% of movement duration to enable inter-individual comparison. System calibration was performed prior to each recording session to maintain reconstruction accuracy within manufacturer-recommended limits.

Statistical Analysis

Because multiple ankle-related variables were examined, the possibility of increased Type I error associated with multiple comparisons was considered. Given the exploratory pilot design of the study and the relatively small sample size, formal multiplicity correction was not applied. Interpretation therefore emphasized standardized effect size magnitude (Hedges' g) and the precision of corresponding 95% confidence intervals.

All statistical analyses were performed using SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated as mean ± standard deviation (mean ± SD). Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test.

Between-group comparisons (highly qualified boxers vs advanced-level boxers) were conducted using independent samples t-tests. Standardized mean differences were calculated using bias-corrected Hedges' g to account for small-sample bias. Ninety-five percent confidence intervals (95% CI) were computed for all effect size estimates. Additionally, eta squared (η^2) values were derived from the t-statistic to estimate the proportion of variance explained by qualification level.

Effect size magnitude was interpreted according to the following thresholds:

- trivial (<0.20)
- small (0.20–0.49)
- moderate (0.50–0.79)
- large (⩾0.80).

Results

Between-group comparisons were conducted to examine qualification-related differences in ankle joint kinematic parameters during execution of the right-hand uppercut (Table 1).

Table 1 presents between-group comparisons

Table 1. Between-group differences in ankle kinematics during the right-hand uppercut.

№	Parameter	Limb	Highly qualified boxers (n=18) (Mean ± SD)	Advanced-level boxers (n=18) (Mean ± SD)	Δ	Hedges g	95% CI		η^2
							Lower	Upper	
1.	Minimum angle (°)	RA	10.83 ± 0.65	9.74 ± 1.98	1.09	0.72	0.04	1.40	0.13
2.	Minimum angle (°)	LA	-6.29 ± 3.37	-4.81 ± 2.94	-1.48	-0.46	-1.12	0.20	0.06
3.	Maximum angle (°)	RA	17.53 ± 1.57	16.42 ± 2.11	1.11	0.55	-0.12	1.22	0.08
4.	Maximum angle (°)	LA	1.10 ± 3.97	-0.85 ± 2.88	1.95	0.52	-0.14	1.18	0.07
5.	ROM (°)	RA	6.91 ± 1.53	6.68 ± 2.02	0.23	0.12	-0.53	0.77	0.00
6.	ROM (°)	LA	6.71 ± 4.64	3.96 ± 3.11	2.75	0.67	-0.00	1.34	0.11
7.	Maximum angular velocity (°/s)	RA	46.72 ± 12.99	41.58 ± 14.26	5.14	0.36	-0.30	1.02	0.03
8.	Maximum angular velocity (°/s)	LA	67.30 ± 48.57	54.22 ± 32.15	13.08	0.30	-0.36	0.96	0.02
9.	Toe-off angle (°)	RA	12.85 ± 2.73	10.92 ± 3.61	1.93	0.55	-0.12	1.22	0.08
10.	Toe-off angle (°)	LA	-2.64 ± 1.32	-1.83 ± 1.75	-0.81	-0.48	-1.14	0.18	0.06
11.	Mid-support angle (°)	RA	14.72 ± 3.10	12.36 ± 2.94	2.36	0.76	0.08	1.44	0.14
12.	Mid-support angle (°)	LA	-3.89 ± 4.41	-2.14 ± 3.02	-1.75	-0.45	-1.11	0.21	0.05
13.	Propulsion distance (mm)	RA	-154.6 ± 86.77	-121.42 ± 73.18	-33.18	-0.40	-1.06	0.26	0.04
14.	Propulsion distance (mm)	LA	-49.38 ± 31.09	-38.55 ± 27.74	-10.83	-0.36	-1.02	0.30	0.03

Note: Data are presented as mean ± SD. Between-group differences were quantified using bias-corrected Hedges' g ($n_1 = n_2 = 18$; df = 34), with 95% confidence intervals reported as lower and upper bounds. Effect size magnitude was interpreted as trivial (<0.20), small (0.20–0.49), moderate (0.50–0.79), and large (⩾0.80). Eta squared (η^2) was calculated as $\eta^2 = t^2 / (t^2 + df)$. RA = right ankle; LA = left ankle; ROM = range of motion.

of ankle joint kinematic parameters during execution of the right-hand uppercut. The analyzed variables included minimum and maximum ankle angles, range of motion (ROM), maximum angular velocity, toe-off angle, mid-support angle, and propulsion distance for both the right and left ankles. Standardized mean differences ranged from trivial to moderate magnitude across the analyzed parameters. The largest effects were observed for the right ankle mid-support angle and the right ankle minimum angle, whereas several additional parameters demonstrated moderate effect sizes with confidence intervals overlapping the null boundary. For most remaining variables, effect sizes were small or accompanied by wide confidence intervals. Several left ankle parameters showed negative effect sizes, indicating slightly greater values in advanced-level boxers. Overall, the pattern of results indicates that qualification-related differences were more apparent in sagittal-plane ankle positioning variables during transitional phases of support, whereas angular velocity and propulsion-related variables showed smaller and less consistent differences.

The integrated effect-size analysis presented in Figures 1–4 summarizes between-group differences in ankle joint kinematic parameters during execution of the right-hand uppercut. Overall, the observed pattern indicates that qualification-related differences are primarily associated with sagittal-plane ankle joint positioning during transitional support phases, whereas variables related to peak

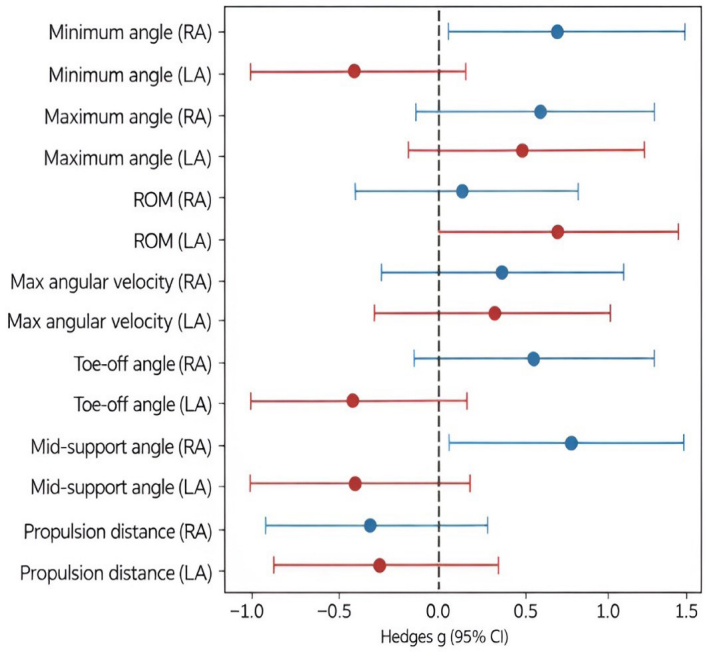

Figure 1. Effect size analysis of ankle joint angles (pre-jump and support phases)

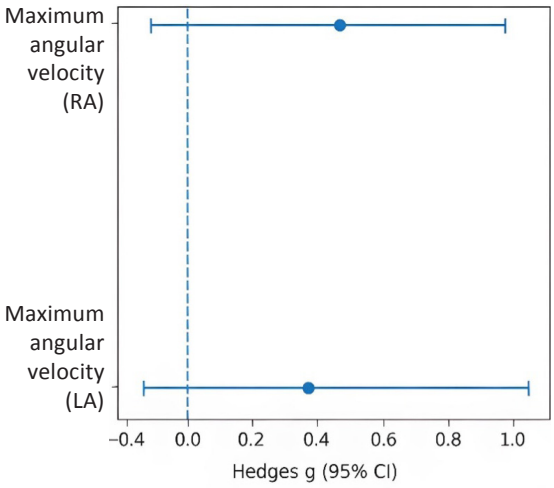

Figure 3. Between-group standardized differences in maximum ankle angular velocity during the right uppercut

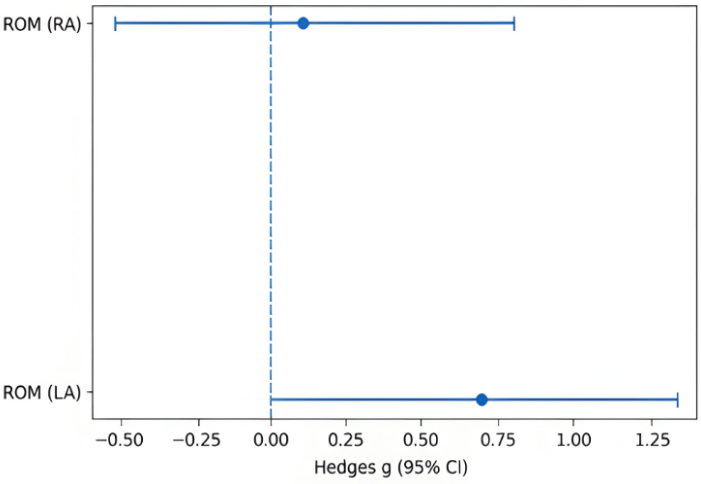

Figure 2. Between-group standardized differences in ankle range of motion (ROM) during the right uppercut

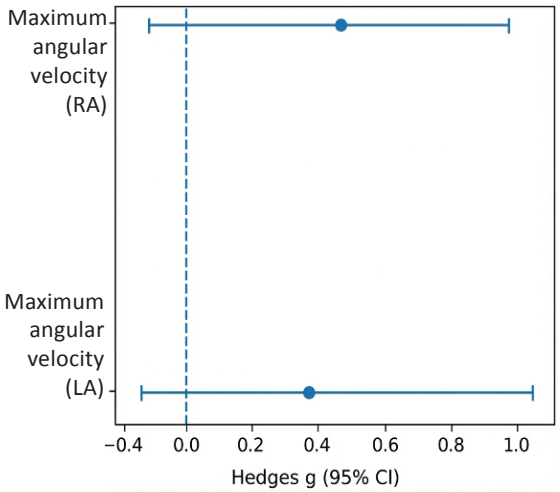

Figure 4. Between-group standardized differences in ankle propulsion distance during the right uppercut

angular velocity and propulsion displacement demonstrate smaller and less consistent effects.

The most consistent between-group difference was observed in the right ankle mid-support angle (Figure 1), where the effect size indicated a moderate directional difference between the examined qualification groups. The confidence interval for this parameter remained above the null boundary. This variable reflects ankle joint positioning during the mid-support phase of the movement, which represents a transitional stage of weight transfer within the lower-limb support sequence during the uppercut. A comparable effect magnitude was observed for the right ankle minimum angle (Figure 1). This parameter describes ankle joint positioning during the preparatory stage of the movement preceding propulsion. Moderate effect sizes were also observed for left ankle range of motion (Figure 2) and for the right ankle maximum and toe-off angles (Figure 1). However, the corresponding confidence intervals overlapped the null boundary, indicating limited precision of these estimates. In contrast, maximum angular velocity parameters (Figure 3) demonstrated small standardized differences between groups, with confidence intervals crossing the null boundary. Similarly, propulsion distance variables (Figure 4) showed small negative effects with confidence intervals overlapping the null boundary. Overall, the figures indicate that between-group differences were more apparent in sagittal-plane ankle positioning variables during transitional phases of the movement, whereas variables describing peak angular velocity and propulsion displacement showed smaller and less consistent differences.

Discussion

This exploratory pilot study examined qualification-related variations in sagittal-plane ankle kinematics during execution of the right-hand uppercut in boxers of high sport qualification. Because of the cross-sectional design and moderate statistical precision, the findings should be interpreted as descriptive patterns rather than causal mechanisms. The results showed that the most apparent differences between groups were observed in ankle joint positioning during transitional support phases of the movement, particularly during mid-support and the preparatory stage preceding propulsion. Greater sagittal-plane ankle positioning was observed in highly qualified boxers during these phases. Moderate effects were also identified for the right ankle maximum and toe-off angles; however, their confidence intervals overlapped zero, indicating limited statistical precision. In contrast, maximum ankle angular velocity and propulsion distance demonstrated small and less consistent differences between groups. These results indicate that qualification-related distinctions may be reflected primarily in ankle joint positioning and phase-specific joint configuration rather than in peak angular velocity or propulsion displacement during the uppercut movement.

Phase-Specific Ankle Stabilization

The right ankle mid-support angle demonstrated the largest standardized difference between groups ($g = 0.76$; $\eta^2 = 0.14$), indicating a moderate effect magnitude. The mid-support phase represents a transitional stage of weight transfer within the lower-limb support sequence. The greater sagittal-plane ankle positioning observed in highly qualified boxers may reflect differences in phase-specific joint alignment during this stage of the uppercut movement.

Although these positional differences may be related to variations in movement control during support and weight transfer, the absence of direct kinetic or neuromuscular measurements means that such interpretations should be considered cautiously and viewed as hypothesis-generating rather than definitive biomechanical explanations.

These observations are broadly consistent with previous biomechanical investigations highlighting the role of intersegmental coordination during punching actions. For example, the results of the study [1] indicated that lower-limb mechanics contribute to the sequencing of movement during punching tasks. However, because the present study focused specifically on ankle joint kinematics, the current findings should be interpreted as reflecting differences in joint positioning strategies rather than direct evidence of force transmission or energy transfer mechanisms.

Joint Excursion and Pre-Propulsive Modulation

Moderate standardized differences were observed in the right ankle minimum angle ($g = 0.72$) and left ankle range of motion (ROM) ($g = 0.67$). These findings indicate that highly qualified boxers demonstrated slightly greater dorsiflexion positioning during the preparatory stage preceding propulsion. Such differences may reflect variation in ankle joint configuration during the loading phase of the movement. However, because the present study did not include kinetic measurements, these observations should be interpreted cautiously and regarded as descriptive rather than mechanistic.

Previous biomechanical investigations have emphasized the importance of lower-limb coordination and joint positioning during the preparatory phases of punching movements [2, 5, 6]. Three-dimensional analyses of punching mechanics have shown that body-segment positioning and temporal coordination influence the mechanical conditions under which propulsion is initiated [2, 5]. In this context, the present findings suggest that ankle joint excursion may contribute to phase-specific movement organization during the execution of the uppercut.

The trivial effect observed in right ankle ROM indicates that not all displacement-related variables vary consistently with qualification level. This pattern suggests that phase-specific joint positioning may be more informative than global displacement measures alone. A similar perspective has been noted in previous biomechanical analyses of punching movements, where overall range of motion was not considered the primary determinant of punching performance in highly trained athletes [7].

Angular Velocity Considerations

Maximum ankle angular velocity demonstrated small standardized differences (g = 0.36 for the right ankle; g = 0.30 for the left ankle), indicating limited differentiation between qualification groups in peak ankle angular velocity during the uppercut movement.

Previous biomechanical studies have suggested that trunk and upper-limb rotational velocities contribute substantially to punching speed and impact performance [10, 16]. Investigations of neuromuscular performance and punch-force production further indicate that explosive activation and coordination of upper- and lower-limb musculature influence strike velocity and force generation in amateur boxers [29]. In addition, recent machine-learning and kinematic classification studies demonstrate that punch recognition and performance analysis rely strongly on coordinated upper-limb velocity patterns and movement sequencing [15]. In this context, the present results may indicate that the ankle joint contributes primarily to movement support and phase-specific positioning rather than serving as the principal source of angular acceleration during the strike.

Similar interpretations have been proposed in earlier biomechanical analyses. For example, the results of the study [10] indicated that lower-limb positioning and coordination during punching movements may contribute to maintaining stability during the support phase. However, because the present study focused solely on kinematic measurements, these interpretations should be considered tentative and hypothesis-generating rather than definitive biomechanical conclusions.

Propulsion-Phase Orientation

Moderate directional differences were observed in the right ankle toe-off angle (g = 0.52; η^2 = 0.12), indicating variation in ankle joint orientation during the propulsion phase. The toe-off event represents the final stage of ground contact preceding the upward acceleration of body segments involved in the punching action. In this context, sagittal-plane ankle orientation at toe-off may reflect differences in movement organization during the transition from support to propulsion.

However, because the present study did not include ground reaction force or impulse measurements, the mechanical implications of these angular tendencies remain uncertain. Consequently, the observed differences should be interpreted as potential variations in joint positioning strategies rather than determinants of force production. Similar observations have been noted in previous biomechanical and analytical investigations of striking techniques. Previous studies have suggested that lower-limb alignment and segmental coordination may influence the mechanical conditions under which force is transmitted through the body segments involved in striking actions [8, 30]. In addition, analytical reviews of combat-sport biomechanics indicate that lower-limb mechanics and kinetic-chain coordination represent important components of striking performance and remain active areas of scientific investigation [31].

Integrative Interpretation

The effect-size distribution suggests that qualification-related differences may be more apparent in sagittal-plane ankle joint positioning during transitional support phases than in peak angular velocity or propulsion displacement variables. This pattern may indicate that variations between qualification groups are more closely associated with phase-specific joint positioning characteristics rather than differences in distal segment velocity.

Importantly, η^2 values ranging from 0.12 to 0.17 indicate that qualification level explained a modest proportion of variance in several ankle kinematic parameters. However, the relatively wide confidence intervals observed across many variables reflect moderate statistical uncertainty. These findings should therefore be interpreted cautiously and considered hypothesis-generating rather than conclusive, particularly given the cross-sectional design and sample size of the present study.

Limitations of the Study and Future Directions

Several limitations should be considered when interpreting the present findings:

1. Although the sample consisted of boxers of high sport qualification (n = 36; 18 per group), the statistical precision of several estimates remained moderate, as reflected in the relatively wide confidence intervals. Consequently, the reported effect sizes should be interpreted as indicative of directional tendencies rather than population-level differences. The cross-sectional design and sample size also limit statistical power.
2. Despite the use of three-dimensional motion capture, the analysis focused primarily on sagittal-plane ankle mechanics. Because the uppercut movement involves multiplanar joint interactions, the exclusion of frontal

and transverse plane contributions restricts the comprehensiveness of the biomechanical interpretation.

3. The study did not include synchronized kinetic measurements such as ground reaction forces or impulse variables. As a result, the relationship between the observed kinematic differences and mechanical output during punching cannot be directly established.
4. Biomechanical analysis was based on a single technically valid maximal trial per participant. While this approach minimized execution variability, it did not allow assessment of intra-individual reliability or movement consistency across repeated attempts.
5. The analysis included multiple kinematic variables within a moderately sized cohort, which may increase statistical uncertainty in effect size estimation. Additionally, although the participants were nationally competing boxers, the findings may not necessarily generalize to athletes of different competitive levels, age groups, or training backgrounds. Potential confounding factors such as training volume, stance dominance, and competitive experience were not controlled in the present analysis.

Future research should extend the present exploratory findings through more comprehensive biomechanical analyses. In particular, integrating synchronized kinetic–kinematic modeling would allow simultaneous examination of joint motion and force-related variables influencing punching performance. Multiplanar joint analysis may provide a more complete description of how qualification-related differences manifest across sagittal, frontal, and transverse planes of motion. Further investigation may also incorporate electromyographic (EMG) assessment of lower-limb muscle activation to examine neuromuscular control strategies involved in ankle stabilization during punching actions. Studies involving larger multicenter samples may improve statistical power and allow validation of the tendencies observed in the present pilot investigation.

Conclusions

From a practical standpoint, the present findings suggest that training strategies aimed at improving uppercut performance may benefit from emphasizing phase-specific ankle stabilization and controlled dorsiflexion–plantarflexion modulation, rather than focusing exclusively on increasing distal joint angular velocity. Such an approach may contribute to more consistent joint positioning during transitional support phases of the striking movement.

The present exploratory pilot study indicates that qualification-related differences in uppercut execution may be associated with ankle joint positioning during transitional support phases of the movement. These observations highlight the potential role of phase-specific joint control in the organization of punching mechanics. However, given the cross-sectional design, moderate statistical precision, and absence of synchronized kinetic measurements, the findings should be interpreted cautiously and regarded as preliminary evidence requiring further confirmation in larger biomechanical investigations.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Lenetsky S, Nates RJ, Brughelli M, Harris NK. Is effective mass in combat sports punching above its weight? *Human Movement Science*, 2015;40: 89–97. https://doi.org/10.1016/j.humov.2014.11.016
2. Lenetsky S, Brughelli M, Nates RJ, Neville JG, Cross MR, Lormier AV. Defining the Phases of Boxing Punches: A Mixed-Method Approach. *Journal of Strength and Conditioning Research*, 2020;34(4): 1040–1051. https://doi.org/10.1519/JSC.0000000000002895
3. Walilko TJ, Viano DC, Bir CA. Biomechanics of the head for Olympic boxer punches to the face. *British Journal of Sports Medicine*, 2005;39(10): 710–719. https://doi.org/10.1136/bjsm.2004.014126
4. Tong-Iam R, Rachanavy P, Lawsirirat C. Kinematic and kinetic analysis of throwing a straight punch: the role of trunk rotation in delivering a powerful straight punch. *Journal of Physical Education and Sport,* 2017;17:2538–2543. https://doi.org/10.7752/jpes.2017.04287
5. Stanley E, Thomson E, Smith G, Lamb KL. An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *International Journal of Performance Analysis in Sport*, 2018;18(5): 835–854. https://doi.org/10.1080/24748668.2018.1525651
6. Dinu D, Louis J. Biomechanical Analysis of the Cross, Hook, and Uppercut in Junior vs. Elite Boxers: Implications for Training and Talent Identification. *Frontiers in Sports and Active Living*, 2020;2: 598861. https://doi.org/10.3389/fspor.2020.598861
7. Piorkowski BA, Lees A, Barton GJ. Single maximal versus combination punch kinematics.

Sports Biomechanics, 2011;10(1): 1–11. https://doi.org/10.1080/14763141.2010.547590
8. Chaabène H, Mkaouer B, Franchini E, Souissi N, Selmi MA, Nagra Y, et al. Physiological Responses and Performance Analysis Difference between Official and Simulated Karate Combat Conditions. *Asian Journal of Sports Medicine*, 2014;5(1): 21–29.
9. Loturco I, Nakamura FY, Artioli GG, Kobal R, Kitamura K, Cal Abad CC, et al. Strength and Power Qualities Are Highly Associated With Punching Impact in Elite Amateur Boxers. *Journal of Strength and Conditioning Research*, 2016;30(1): 109–116. https://doi.org/10.1519/JSC.0000000000001075
10. Liu Y, Zhu Z, Chen X, Deng C, Ma X, Zhao B. Biomechanics of the lead straight punch of different level boxers. *Frontiers in Physiology*, 2022;13:1015154. https://doi.org/10.3389/fphys.2022.1015154
11. Liu Y, Li L, Yan X, He X, Zhao B. Biomechanics of the lead straight punch and related indexes between sanda fighters and boxers from the perspective of cross-border talent transfer. *Frontiers in Physiology*, 2023;13: 1099682. https://doi.org/10.3389/fphys.2022.1099682
12. Stewart C, Cornett R, Baker JS, Gu Y, Dutheil F, Ugbolue UC. The Role of Lower Limb Kinetics in Boxing Punches and the Impact of Fatigue on Biomechanical Performance. *Bioengineering*, 2025;12(12): 1355. https://doi.org/10.3390/bioengineering12121355
13. Dunn EC, Humberstone CE, Franchini E, Iredale KF, Blazevich AJ. Relationships Between Punch Impact Force and Upper- and Lower-Body Muscular Strength and Power in Highly Trained Amateur Boxers. *Journal of Strength & Conditioning Research*, 2022;36(4): 1019–1025. https://doi.org/10.1519/JSC.0000000000003585
14. Cizmic D, Hoelbling D, Baranyi R, Breiteneder R, Grechenig T. Smart Boxing Glove "RD α": IMU Combined with Force Sensor for Highly Accurate Technique and Target Recognition Using Machine Learning. *Applied Sciences*, 2023;13(16): 9073. https://doi.org/10.3390/app13169073
15. Manoharan S, Warburton J, Hegde RS, Srinivasan R, Srinivasan B. An active machine learning framework for automatic boxing punch recognition and classification using upper limb kinematics. Zhang, X (ed.) *PLOS One*, 2025;20(5): e0322490. https://doi.org/10.1371/journal.pone.0322490
16. Xue H, Han C, Zhu D. Limb biomechanics in combat sports: insights from wearable sensor technology. *Frontiers in Bioengineering and Biotechnology*, 2025;13: 1663592. https://doi.org/10.3389/fbioe.2025.1663592
17. Xu Q, Mao R, Xi C. A comparative analysis of punching in boxing and sanda: kinematic differences based on the cross and uppercut. *Frontiers in Sports and Active Living*, 2024;6: 1441470. https://doi.org/10.3389/fspor.2024.1441470
18. Kacprzak J, Mosler D, Tsos A, Wąsik J. Biomechanics of Punching—The Impact of Effective Mass and Force Transfer on Strike Performance. *Applied Sciences*, 2025;15(7): 4008. https://doi.org/10.3390/app15074008
19. Beattie K, Ruddock AD. The Role of Strength on Punch Impact Force in Boxing. *Journal of Strength & Conditioning Research*, 2022;36(10): 2957–2969. https://doi.org/10.1519/JSC.0000000000004252
20. Del Vecchio FB, Hirata SM, Franchini E. A Review of Time-Motion Analysis and Combat Development in Mixed Martial Arts Matches at Regional Level Tournaments. *Perceptual and Motor Skills*, 2011;112(2): 639–648. https://doi.org/10.2466/05.25.PMS.112.2.639-648
21. Khalmuxamedov R, Tajibaev S, Yarashev K, Ismoilov G, Gatt I, Anashov V, et al. Analysis of Kinetic Energy (KE) and Angular Values by Phase of Kinematic Indicators of Direct Head Blows by Boxers of Various Categories. *Slobozhanskyi Herald Sci Sport,* 2025;29(3): 213–223. https://doi.org/10.15391/snsv.2025-3.03
22. Kumar S, Pradhan P, Minu T, Saini P, Babu TS, Bagchi A, et al. Activation of upper- and lower-limb muscles during hook punch using lead- and rear-arm. *Journal of Human Sport and Exercise*, 2025;20(3): 989–999. https://doi.org/10.55860/1ha8tf90
23. Finlay MJ, Page RM, Greig M, Bridge CA. Test-retest reliability and sensitivity of senior elite amateur boxers maximal punch force, as quantified by a vertically mounted force plate. Ruddock A (ed.) *PLOS ONE*, 2023;18(8): e0289791. https://doi.org/10.1371/journal.pone.0289791
24. Menzel T, Potthast W. Validation of a Novel Boxing Monitoring System to Detect and Analyse the Centre of Pressure Movement on the Boxer's Fist. *Sensors*, 2021;21(24): 8394. https://doi.org/10.3390/s21248394
25. Tajibaev SS, Ismoilov G, Yusupova N, Abdukhamidov R, Nabiev S, Ovsyannikov A, et al. The design of a striking dummy and the theoretical foundations of martial arts strikes. *Acta of Bioengineering and Biomechanics*, 2024;26(3). https://doi.org/10.37190/ABB-02466-2024-04
26. Tajibaev S, Omonov D, Khojiev S, Gafforov N, Mannonov J, Makhkamov S, et al. Increasing the maximum angular velocity of the jab punch in amateur boxers. *Pedagogy of Physical Culture and Sports*, 2026;30(1): 38–51. https://doi.org/10.15561/26649837.2026.0104
27. Wu G, Cavanagh PR. ISB recommendations for standardization in the reporting of kinematic data. *Journal of Biomechanics*, 1995;28(10): 1257–1261. https://doi.org/10.1016/0021-9290(95)00017-C
28. Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics*, 2002;35(4): 543–548. https://doi.org/10.1016/S0021-9290(01)00222-6
29. Finlay MJ, Greig M, Bridge CA, Page RM. Post-Activation Performance Enhancement of Punch Force and Neuromuscular Performance in Amateur Boxing: Toward a More Individualized and "Real-World" Approach. *Journal of Strength & Conditioning Research*, 2024;38(6): 1063–1071.

https://doi.org/10.1519/JSC.0000000000004740
30. Perkins P, Jamieson A, Spratford W, Hahn A. Pneumatic Boxing Glove Reduces Upward Drift in Peak Force and Loading Rate over a Long Series of Impacts. *World Journal of Engineering and Technology*, 2019;07(01): 18–53. https://doi.org/10.4236/wjet.2019.71002
31. Podrigalo LV, Shi K, Podrihalo OO, Volodchenko OA, Halashko OI. Main research areas in kickboxing investigations: an analysis of the scientific articles of the Web of Science Core Collection. *Pedagogy of Physical Culture and Sports*, 2022;26(4):244–259. https://doi.org/10.15561/26649837.2022.0404

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ORIGINAL ARTICLE

Effects of a sequenced stretching and massage recovery protocol on physiological and perceptual responses after high-intensity exercise in collegiate football players

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

Abstract

Background and Study Aim: Short-term recovery occurs between successive exercise bouts in intermittent sports. Intense exercise is followed by metabolic accumulation, inflammatory responses, and increased muscle discomfort. Static stretching and massage are used as recovery strategies after exercise. Despite the use of these approaches, their relative effectiveness in enhancing acute recovery remains a subject of practical consideration. This study examined whether a sequenced combination of static stretching followed by massage enhances acute recovery more than single-modality interventions or passive rest.

Material and Methods: Forty-eight male collegiate football players (19–22 years) were randomly allocated to sport massage (SM), static stretching (SS), sequenced combination (SC), or passive control (CON). Participants completed an incremental treadmill test to induce metabolic and inflammatory stress. A 10-minute recovery intervention was applied immediately post-exercise. Blood lactate, interleukin-6 (IL-6), creatine kinase (CK), perceived muscle pain (VAS), and knee flexion range of motion (ROM) were assessed pre-exercise, post-exercise, and post-recovery. Data were analyzed using ANCOVA (post-exercise as a covariate), one-way ANOVA of change scores, and linear mixed-effects models ($p < 0.05$).

Results: No baseline differences were observed between groups ($p \geqslant 0.724$). Significant Group × Time interactions were detected for lactate, IL-6, CK, VAS, and ROM ($p \leqslant 0.003$; $\eta^2p = 0.20–0.28$), indicating distinct recovery trajectories. After adjustment for post-exercise values, SC showed lower post-recovery lactate (5.18 mmol·L^{-1}) compared with CON (8.74 mmol·L^{-1}; $p < 0.001$; $d = 0.96$) and SS (7.01 mmol·L^{-1}; $p = 0.004$; $d = 0.71$). IL-6 and CK were significantly reduced in SC compared with CON ($p \leqslant 0.003$; $d = 0.82–0.88$). Perceived pain was markedly lower in SC (2.4 cm) than in CON (5.6 cm; $p < 0.001$; $d = 1.02$). ROM improved most in SC (Δ +3.2°), exceeding SS and CON ($p \leqslant 0.039$). Change-score analyses confirmed a greater recovery magnitude in SC across all outcomes ($\eta^2 = 0.33–0.44$).

Conclusions: A sequenced stretch–massage protocol produces superior short-term metabolic, inflammatory, and perceptual recovery compared with passive rest. It also demonstrates moderate advantages over single-modality strategies. This approach offers a practical and physiologically supported recovery method for intermittent sport settings.

Keywords: massage therapy, static stretching, acute recovery, interleukin-6, creatine kinase, lactate clearance

Introduction

Recovery processes influence the restoration of physiological and perceptual states after intensive exercise. In intermittent sports, repeated high-intensity efforts are commonly associated with metabolic accumulation, inflammatory responses, and temporary increases in muscle discomfort. These responses may affect movement range, perceived pain, and the readiness of athletes to perform subsequent activity. Various post-exercise strategies are therefore applied to facilitate recovery and support the return of functional capacity between exercise bouts.

Additionally, high-intensity intermittent sports such as football impose substantial metabolic, mechanical, and inflammatory stress within short competitive windows. Contemporary match analyses show repeated sprint efforts, accelerations, and high-

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intensity transitions that markedly elevate blood lactate, pro-inflammatory cytokines, and indirect markers of muscle damage [1, 2]. Acute elevations in interleukin-6 (IL-6) and creatine kinase (CK) reflect metabolic strain and sarcolemmal disruption. These responses are frequently accompanied by increased perceived muscle soreness and transient reductions in range of motion (ROM) [3, 4]. In congested match schedules, or even within halftime intervals of approximately 10–15 minutes, rapid recovery is therefore strategically important.

Among practical recovery strategies, sport massage and static stretching remain widely adopted due to feasibility and minimal equipment demands. Massage has been proposed to enhance venous return, increase local blood flow, and modulate inflammatory signaling pathways [5]. Recent mechanistic evidence suggests that post-exercise massage may attenuate pro-inflammatory signaling cascades and influence immune-related gene expression in skeletal muscle [6, 7]. Meta-analytic findings indicate reductions in perceived muscle soreness following massage. However, effects on metabolic clearance and performance recovery remain variable [8, 9].

Static stretching, conversely, is primarily implemented to reduce passive stiffness and improve viscoelastic compliance of the muscle–tendon unit. Contemporary research confirms its effectiveness in enhancing ROM, likely through changes in stretch tolerance and mechanical properties rather than structural elongation per se [10, 11]. However, evidence supporting stretching as a metabolic or inflammatory recovery strategy remains inconclusive [12].

Despite extensive investigation of massage and stretching as independent interventions, the potential interaction between these modalities when applied sequentially remains a relevant conceptual consideration. Most trials examine single-modality interventions compared with passive rest. They rarely address whether structured sequencing may influence recovery kinetics. From a mechanobiological perspective, stretching may transiently modify extracellular matrix stiffness and muscle viscoelastic behavior. This response may prime tissue responsiveness to subsequent mechanical loading [13]. Massage applied after such viscoelastic priming could enhance microcirculatory exchange, facilitate metabolite redistribution, and modulate inflammatory signaling more effectively than either modality alone [14].

Analysis of research findings has shown that post-exercise recovery strategies such as massage and static stretching influence physiological and perceptual responses following intensive physical activity. Researchers report that these modalities are associated with changes in metabolic by-product clearance, inflammatory signaling, perceived muscle discomfort, and joint range of motion during the early recovery period. At the same time, the organization of recovery interventions remains a practical consideration in intermittent sports settings where recovery time is limited and several physiological processes occur simultaneously. In this context, the potential interaction between different recovery modalities and their sequencing continues to attract attention in applied recovery practice. Additionally, many studies assess recovery using isolated indicators, frequently focusing on perceptual soreness, whereas metabolic, inflammatory, muscle damage, and neuromechanical responses are often considered separately. This study examined whether a sequenced combination of static stretching followed by massage improves short-term recovery compared with either modality alone or passive rest after high-intensity exercise.

Materials and Methods

Participants

A total of 72 male collegiate football players from Universitas Negeri Surabaya were initially assessed for eligibility. Following screening, 24 athletes were excluded because they did not meet the inclusion criteria or declined to participate. Consequently, 48 participants (aged 19–22 years) met the eligibility criteria and were enrolled in the study. The participant recruitment, screening, allocation, follow-up, and analysis procedures are illustrated in Figure 1 (CONSORT flow diagram).

Participants were required to meet the following inclusion criteria: (1) active collegiate football players who trained at least three times per week, (2) aged between 19 and 22 years, and (3) free from musculoskeletal injury during the previous three months. Exclusion criteria included current lower-limb pain, metabolic disorders, or the use of anti-inflammatory medication within the preceding three months.

Sample size was determined a priori using G*Power software (version 3.1) based on a repeated-measures experimental design (effect size f = 0.30, $\alpha = 0.05$, statistical power = 0.80, correlation among repeated measures = 0.50). The analysis indicated a minimum requirement of 44 participants. To account for potential attrition and ensure adequate statistical power, 48 participants were included in the final sample.

The study followed the CONSORT guidelines for randomized trials and adhered to the Declaration of Helsinki. The study protocol was reviewed and approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Negeri Semarang (No. 068/KEPK/FK/KLE/2024; approval date: January 29, 2024). Ethical clearance was granted in accordance with the WHO 2011 standards and the 2016 CIOMS guidelines. All participants provided

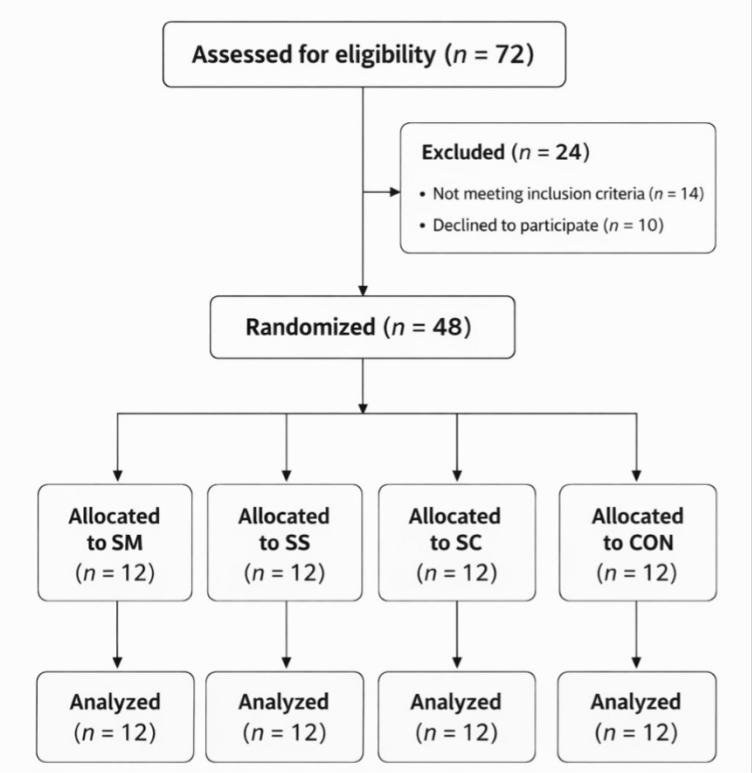

Figure 1. CONSORT flow diagram showing participant recruitment, randomization, allocation, follow-up, and analysis.

written informed consent prior to participation.

Research Design

This study employed a randomized controlled parallel-group design with repeated measures to examine acute physiological, inflammatory, and perceptual recovery responses following high-intensity exercise. The experimental model was designed to simulate short-term half-time recovery conditions in intermittent sports. Participants were randomly allocated to four groups: Sport Massage (SM), Static Stretching (SS), Sequenced Combination (SC), and Passive Recovery Control (CON).

All experimental sessions were conducted in a controlled laboratory environment (22–24°C; 50–60% relative humidity) at Universitas Negeri Surabaya between 07:00 and 11:00 a.m. to minimize circadian variation in metabolic and inflammatory responses. Participants were instructed to refrain from strenuous exercise for 48 hours, avoid caffeine and alcohol for 24 hours, and maintain habitual sleep patterns (⩾7 hours) prior to testing. Upon arrival, hydration status was checked, and participants rested quietly in a seated position for 10 minutes before baseline assessments.

Following the resting period, baseline (pre-exercise) measurements were obtained. Resting heart rate was recorded. Capillary blood samples were then collected from the fingertip for lactate analysis. A 5-mL venous blood sample was drawn from the antecubital vein to determine interleukin-6 (IL-6) and creatine kinase (CK). Knee flexion range of motion (ROM) of the dominant leg was measured using a universal goniometer. Perceived muscle pain was assessed using a 10-cm Visual Analogue Scale (VAS). All measurements were performed by the same trained assessor to ensure consistency.

Participants then performed an incremental treadmill protocol designed to induce acute metabolic and inflammatory stress. The protocol began at 8 $km \cdot h^{-1}$ with a fixed 1% incline. Speed was increased by 1 $km \cdot h^{-1}$ every two minutes until volitional exhaustion or attainment of ⩾90% age-predicted HRmax. Heart rate was continuously monitored using chest-strap telemetry. This exercise model has been shown to elevate blood lactate concentration and stimulate acute cytokine responses, including IL-6 release [15, 16]. Immediately (within two minutes) after cessation of exercise, post-exercise measurements were repeated in the following order: capillary blood lactate, venous blood sampling (IL-6 and CK), VAS assessment, and ROM measurement. Participants were then randomly allocated via computer-generated block randomization to one of four groups: Sport Massage (SM), Static Stretching (SS), Sequenced Combination (SC), or Passive Recovery Control (CON). Allocation was concealed using sealed opaque envelopes prepared by an independent researcher. Outcome assessors and laboratory technicians were blinded to group allocation.

The assigned recovery intervention was administered immediately after post-exercise

measurements and lasted 10 minutes. All interventions targeted bilateral lower-extremity musculature (hamstrings, quadriceps, gastrocnemius, and hip flexors) to simulate short-term half-time recovery conditions in intermittent sports. Massage pressure was standardized at moderate intensity (5–6/10 perceived pressure), while stretching intensity was applied to the point of mild discomfort without pain. For the Sequenced Combination (SC) protocol, stretch durations were standardized using a metronome (60 bpm) to ensure consistent six-, seven-, and eight-count timing sequences.

Immediately following the 10-minute recovery period, post-recovery measurements were obtained in the same order as previous assessments. Venous blood samples were centrifuged at 3000 rpm for 10 minutes, and serum was stored at −80°C until enzyme-linked immunosorbent assay (ELISA) analysis for IL-6. CK was analyzed using an automated biochemical analyzer. All biochemical assays were performed in duplicate, and intra-assay coefficients of variation were maintained below 5%. Range of motion measurements demonstrated high intra-rater reliability (ICC > 0.90). The recovery intervention protocols for each group are presented in Table 1.

Measurement

Heart rate (HR) was continuously monitored during the exercise protocol using a validated chest-strap telemetry system (Polar H10) to ensure that participants reached ⩾90% of age-predicted HRmax. Continuous HR monitoring is considered a reliable method for quantifying cardiovascular load during high-intensity exercise [17, 18]. Capillary blood lactate concentration was measured at three time points (pre-exercise, immediately post-exercise, and post-recovery) using a portable lactate analyzer (Lactate Pro 2). Finger-prick samples were collected using sterile lancets, and analysis was performed immediately according to manufacturer guidelines [19].

To assess inflammatory and muscle damage responses, venous blood samples (5 mL) were collected from the antecubital vein at the same three time points. Samples were allowed to clot, centrifuged at 3000 rpm for 10 minutes, and serum was stored at −80°C until analysis. Interleukin-6 (IL-6) concentrations were determined using enzyme-linked immunosorbent assay (ELISA) [20], while creatine kinase (CK) activity was analyzed using an automated biochemical analyzer [21]. IL-6 is recognized as a cytokine responsive to acute exercise-induced metabolic stress, and CK is widely used as an indirect marker of muscle membrane disruption [22]. All biochemical assays were performed in duplicate, with intra-assay coefficients of variation maintained below 5%.

Perceived muscle pain was assessed using a 10-cm Visual Analogue Scale (VAS), anchored by "no pain" (0) and "worst imaginable pain" (10). The VAS is a valid and reliable tool for measuring acute exercise-induced muscle discomfort. Participants marked their pain level independently, and the score was recorded in centimeters [23]. Knee flexion range of motion (ROM) was measured using a universal goniometer with participants in a standardized supine position. Anatomical landmarks were identified prior to measurement, and passive flexion was applied until a firm end-feel was reached. Goniometric assessment of ROM demonstrates high intra-rater reliability when standardized procedures

Table 1. Recovery intervention protocol across groups

Group	Duration	Procedure Description	Muscle Target	Intensity Standardization	Theoretical Rationale
Sport Massage (SM)	10 min	Sequential effleurage (2 min), petrissage (3 min), tapotement (2 min), and shaking (3 min) applied rhythmically	Bilateral hamstrings, quadriceps, gastrocnemius, and hip flexors	Moderate pressure (5–6/10); ~30 strokes/min	Enhance venous return, microvascular perfusion, and neuromuscular relaxation
Static Stretching (SS)	10 min	Passive static stretches (20 s hold × 2 sets per muscle group) with controlled transitions	Same muscle groups	Mild discomfort without pain	Reduce passive muscle stiffness and improve viscoelastic compliance
Sequenced Combination (SC)	10 min	Phase 1: 6-count passive stretch → shaking + friction; Phase 2: 7-count stretch → tapotement + shaking + rubbing; Phase 3: 8-count stretch → effleurage (closing)	Same muscle groups	Stretch counts controlled by a metronome (60 bpm); moderate manual pressure	Sequenced viscoelastic priming followed by mechanical circulatory stimulation and inflammatory modulation
Passive Control (CON)	10 min	Seated quiet rest; no physical manipulation	—	No intervention	Natural recovery comparison

are followed [24].

All measurements were obtained in a fixed order (lactate, venous sampling, VAS, ROM) at each time point to minimize procedural variability. Outcome assessors and laboratory technicians were blinded to group allocation to reduce detection bias. Data were recorded on standardized laboratory sheets and double-checked before statistical analysis.

Statistical Analysis

All statistical analyses were performed using SPSS version 26 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was examined using Levene's test. Baseline comparability between groups was evaluated using one-way ANOVA.

The primary analysis used a linear mixed-effects model for repeated measures, with Group (SC, SM, SS, CON), Time (baseline, post-exercise, recovery), and the Group × Time interaction included as fixed effects, and participants treated as a random intercept. Models were estimated using restricted maximum likelihood (REML) to account for within-subject correlations.

Blood lactate concentration was defined as the primary outcome, while IL-6, CK, VAS pain scores, and ROM were treated as secondary outcomes. When significant interactions were detected, Bonferroni-adjusted pairwise comparisons were performed. Estimated marginal means and 95% confidence intervals (CIs) were reported.

Effect sizes were calculated using partial eta squared (η^2p) for model effects and Cohen's d for pairwise comparisons. Effect size magnitudes were interpreted using conventional thresholds (small = 0.2, medium = 0.5, large = 0.8). Additional ANCOVA and change-score ANOVA analyses were conducted as secondary robustness checks. All participants completed the study protocol, and no missing outcome data were observed. Analyses were therefore performed using complete datasets.

Results

All participants completed the experimental protocol without adverse events. Assumptions of normality and homogeneity were satisfied for all variables ($p > 0.05$). Descriptive statistics and baseline comparisons are presented in Table 2.

Between-group differences at baseline were examined using one-way ANOVA. As shown in Table 2, no significant baseline differences were observed across groups for lactate, IL-6, CK, or ROM ($p \geqslant 0.724$; $\eta^2 \leqslant 0.03$), indicating baseline comparability between groups.

Post-recovery outcomes adjusted for post-exercise values are presented in Table 3.

Adjusted post-recovery means were estimated using ANCOVA with post-exercise values as covariates. Homogeneity of regression slopes was verified (Group × Covariate interaction $p > 0.05$). As shown in Table 3, significant between-group differences were observed across all physiological and perceptual outcomes ($p \leqslant 0.005$). Effect sizes ranged from $\eta^2p = 0.16$ to 0.27.

Bonferroni-adjusted pairwise comparisons are presented in Table 4.

As shown in Table 4, Bonferroni-adjusted comparisons indicated significant differences between SC and CON across all outcomes ($p \leqslant 0.003$; $d = 0.82–1.02$). Differences between SC and SS were observed for lactate, VAS, and ROM ($p \leqslant 0.039$), whereas comparisons between SC and SM were not statistically significant ($p \geqslant 0.062$).

Between-group differences in recovery magnitude (Δ scores) are presented in Table 5.

As shown in Table 5, change-score analysis indicated significant between-group differences across all variables ($p < 0.001$; $\eta^2 = 0.33–0.44$).

Fixed effects from the linear mixed-effects model are presented in Table 6.

Table 2. Baseline Characteristics of Participants

Variable	SM (n=12)	SS (n=12)	SC (n=12)	CON (n=12)	F(3,44)	p	η^2
Lactate Pre (mmol·L^{-1})	1.52 ± 0.28	1.49 ± 0.31	1.55 ± 0.26	1.50 ± 0.30	0.24	0.867	0.02
IL-6 Pre (pg·mL^{-1})	1.12 ± 0.21	1.09 ± 0.25	1.15 ± 0.22	1.10 ± 0.24	0.16	0.923	0.01
CK Pre (U·L^{-1})	148.6 ± 17.9	151.2 ± 19.4	149.3 ± 18.6	150.5 ± 16.8	0.07	0.975	0.01
ROM Pre (°)	130.8 ± 3.4	129.9 ± 3.8	131.2 ± 3.1	130.1 ± 3.6	0.44	0.724	0.03

Note. Data are presented as mean ± SD.

Table 3. Post-Recovery Outcomes Adjusted for Post-Exercise Values (ANCOVA)

Variable	SM Adj. Mean (95% CI)	SS Adj. Mean (95% CI)	SC Adj. Mean (95% CI)	CON Adj. Mean (95% CI)	F(3,43)	p	Partial η^2
Lactate	6.12 (5.48–6.76)	7.01 (6.32–7.70)	5.18 (4.60–5.76)	8.74 (7.96–9.52)	6.84	0.001	0.23
IL-6	3.21 (2.73–3.69)	3.84 (3.32–4.36)	2.71 (2.27–3.15)	4.92 (4.34–5.50)	5.97	0.002	0.19
CK	214.6 (189.5–239.7)	225.1 (198.4–251.8)	198.3 (174.0–222.6)	247.5 (216.6–278.4)	4.88	0.005	0.16
VAS	3.2 (2.6–3.8)	3.8 (3.1–4.5)	2.4 (1.9–2.9)	5.6 (4.8–6.4)	7.21	<0.001	0.27
ROM	129.7 (127.4–132.0)	128.9 (126.5–131.3)	132.4 (130.2–134.6)	125.6 (122.9–128.3)	6.15	0.001	0.20

Note. Data are presented as adjusted post-recovery means with 95% confidence intervals.

Table 4. Bonferroni-Adjusted Pairwise Comparisons (Adjusted Means)

Variable	Comparison	Mean Difference	95% CI	Cohen's d	p
	SC vs CON	−3.02	−4.21 to −1.83	0.96	<0.001
Lactate	SC vs SS	−1.84	−3.02 to −0.66	0.71	0.004
	SC vs SM	−0.98	−2.01 to 0.05	0.45	0.062
	SC vs CON	−1.28	−2.11 to −0.45	0.82	0.002
IL-6	SC vs SS	−0.74	−1.52 to 0.04	0.48	0.068
	SC vs SM	−0.39	−1.12 to 0.34	0.29	0.284
	SC vs CON	−34.6	−57.8 to −11.4	0.88	0.003
CK	SC vs SS	−21.4	−43.1 to 0.3	0.52	0.054
	SC vs SM	−12.2	−32.8 to 8.4	0.30	0.241
	SC vs CON	−2.31	−2.89 to −1.73	1.02	<0.001
VAS	SC vs SS	−0.93	−1.56 to −0.30	0.68	0.006
	SC vs SM	−0.52	−1.10 to 0.06	0.41	0.072
	SC vs CON	+4.18	1.72 to 6.64	0.84	0.002
ROM	SC vs SS	+2.36	0.12 to 4.60	0.56	0.039
	SC vs SM	+1.41	−0.71 to 3.53	0.33	0.186

Note. Mean differences are based on adjusted means from ANCOVA. Cohen's d values are reported as effect sizes.

Table 5. Between-Group Differences in Recovery Magnitude (Δ Scores)

Variable	SM (Mean ± SD)	SS (Mean ± SD)	SC (Mean ± SD)	CON (Mean ± SD)	F(3,44)	p	η^2
Δ Lactate (mmol·L^{-1})	3.8 ± 0.9	3.1 ± 0.8	4.7 ± 1.0	1.6 ± 0.7	9.42	<0.001	0.39
Δ IL-6 (pg·mL^{-1})	1.9 ± 0.6	1.5 ± 0.5	2.4 ± 0.7	0.9 ± 0.4	8.11	<0.001	0.36
Δ CK (U·L^{-1})	58.3 ± 18.4	47.6 ± 16.9	72.8 ± 20.2	29.5 ± 14.3	7.25	<0.001	0.33
Δ VAS	2.8 ± 0.7	2.3 ± 0.6	3.5 ± 0.8	1.2 ± 0.5	11.63	<0.001	0.44
Δ ROM (°)	+1.8 ± 1.4	+1.1 ± 1.3	+3.2 ± 1.6	−0.5 ± 1.2	8.94	<0.001	0.38

Note. Change scores (Δ) were calculated as post-exercise minus post-recovery values (ROM reversed to reflect improvement).

Table 6. Fixed Effects from Linear Mixed-Effects Model

Variable	Fixed Effect	F(df)	p	Partial η^2	95% CI
	Time	F(2,88) = 142.6	<0.001	0.76	—
Lactate	Group	F(3,44) = 5.21	0.003	0.26	—
	Group × Time	F(6,88) = 4.83	<0.001	0.25	0.11–0.39
	Time	F(2,88) = 96.4	<0.001	0.69	—
IL-6	Group	F(3,44) = 4.11	0.012	0.22	—
	Group × Time	F(6,88) = 3.94	0.002	0.21	0.07–0.34
	Time	F(2,88) = 88.7	<0.001	0.67	—
CK	Group	F(3,44) = 3.47	0.023	0.19	—
	Group × Time	F(6,88) = 3.62	0.003	0.20	0.06–0.33
	Time	F(2,88) = 158.3	<0.001	0.78	—
VAS	Group	F(3,44) = 6.04	0.001	0.29	—
	Group × Time	F(6,88) = 5.71	<0.001	0.28	0.14–0.41
	Time	F(2,88) = 71.2	<0.001	0.62	—
ROM	Group	F(3,44) = 4.88	0.005	0.25	—
	Group × Time	F(6,88) = 4.26	0.001	0.23	0.09–0.36

Note. Linear mixed-effects models included fixed effects for Group, Time, and the Group × Time interaction, with a random intercept for participants. Partial eta squared (η^2p) indicates effect size.

As shown in Table 6, significant main effects of Time were observed for all variables ($p < 0.001$; $\eta^2p = 0.62–0.78$). Significant Group × Time interactions were also detected across all outcomes ($p \leqslant 0.003$; $\eta^2p = 0.20–0.28$).

Longitudinal recovery trajectories across the three measurement time points are illustrated in Figure 2. As shown in Figure 2, all groups demonstrated marked post-exercise increases in lactate, IL-6, CK, and VAS, accompanied by a reduction in ROM, confirming the physiological perturbation induced by the exercise protocol.

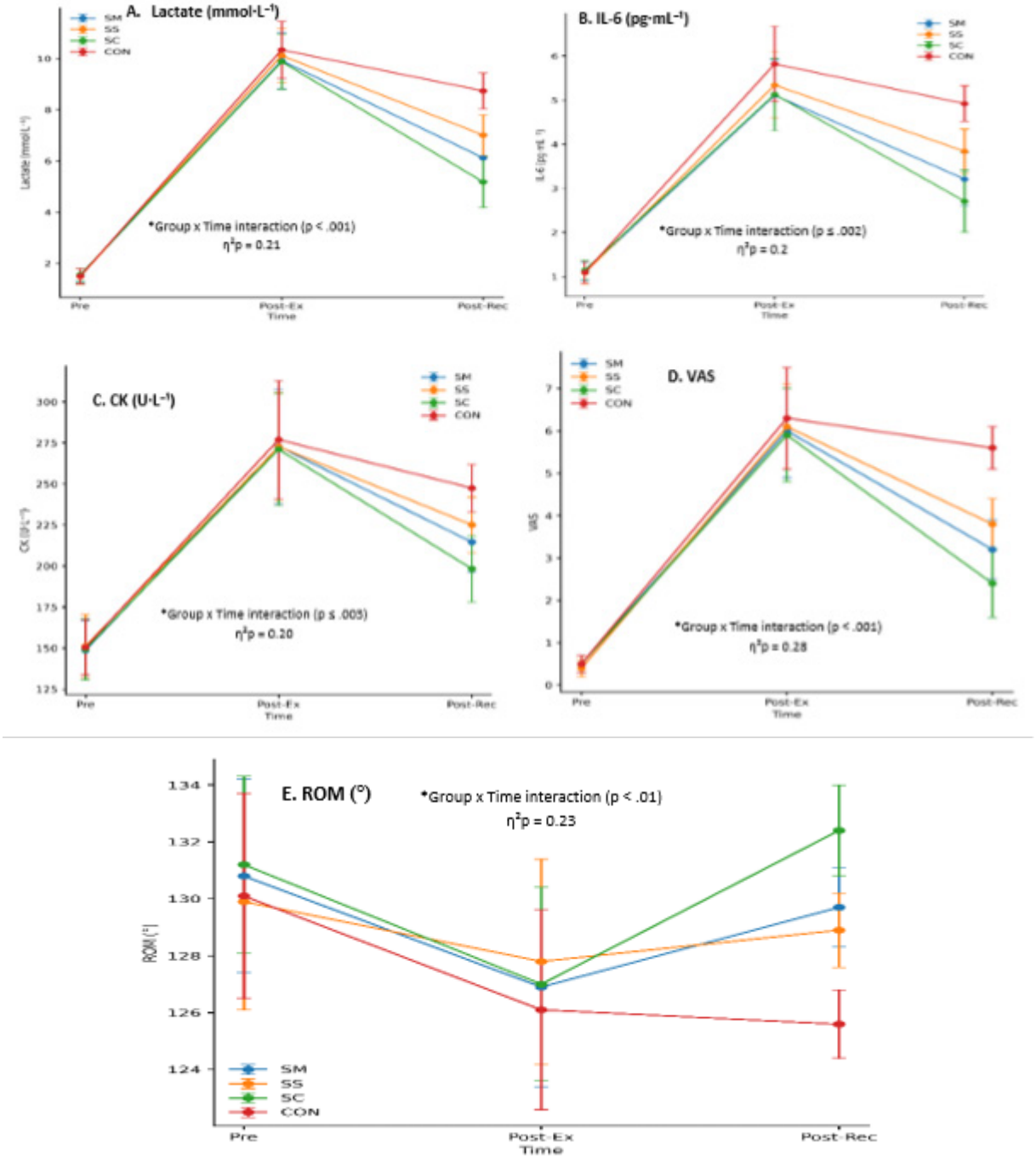

Figure 2. Recovery trajectories of physiological and perceptual responses following high-intensity exercise across intervention groups.

During the recovery phase, the SC group showed a greater reduction in lactate, IL-6, CK, and perceived muscle pain, as well as a greater restoration of ROM compared with the other intervention groups.

Discussion

The present study investigated whether a sequenced combination of massage and stretching (SC) provides greater short-term recovery than sport massage alone (SM), static stretching alone (SS), or passive recovery (CON) following high-intensity treadmill exercise. The results indicate that SC was associated with greater reductions in blood lactate, IL-6, CK, and perceived muscle pain, as well as greater restoration of ROM compared with the other recovery conditions. Significant Group × Time interactions observed in the mixed-effects models indicate differences in recovery trajectories between the intervention groups rather than isolated differences at a single time point.

The exercise protocol induced physiological responses, as reflected by significant main effects of Time for lactate, IL-6, and CK (η^2p = 0.62–0.78). These responses indicate that the SC

demonstrated lower adjusted post-recovery lactate levels compared with CON (d = 0.96) and SS (d = 0.71), along with a larger change-score reduction (Δ = 4.7 ± 1.0 mmol·L^{-1}; η^2 = 0.39). These results indicate differences in post-exercise metabolic responses between recovery conditions. Massage techniques such as effleurage and petrissage have been associated with increased venous return and local blood flow, which may facilitate metabolite redistribution and oxidation. Evidence regarding the effect of massage on lactate removal remains inconsistent, although some studies report that increased local circulation may support metabolite clearance when applied after exercise [25, 26]. The addition of stretching in the SC protocol may influence tissue viscoelastic properties, which could affect metabolite redistribution during recovery. However, the present study did not directly assess microcirculatory responses.

IL-6 responses showed a similar trend, with SC producing lower adjusted concentrations than CON (d = 0.82). Although IL-6 is often described as a pro-inflammatory cytokine, exercise-induced IL-6 also participates in regulatory and metabolic signaling processes [27, 28]. The lower post-recovery values observed in SC may reflect differences in the regulation of acute inflammatory responses. Mechanical stimulation from massage has been reported to influence inflammatory signaling pathways in skeletal muscle [6], whereas stretching may reduce passive stiffness and related nociceptive input [29]. The sequential application of these modalities may therefore influence inflammatory responses, although the cellular mechanisms cannot be determined from the present data.

Similarly, CK levels, an indirect marker of sarcolemmal disruption, were lower in the SC group (Δ = 72.8 ± 20.2 U·L^{-1}; η^2 = 0.33). Acute CK responses are influenced by several factors, including membrane permeability and perfusion. The combined intervention may therefore be associated with differences in physiological recovery processes, including metabolite clearance and fatigue-related responses. Perceived muscle pain showed the largest effect among the analyzed variables (η^2 = 0.44 for change scores), with SC demonstrating lower scores than CON (d = 1.02) and SS (d = 0.68). These observations are consistent with studies reporting that massage can influence nociceptive processing through mechanoreceptor stimulation and possible activation of descending inhibitory pathways [30]. Stretching may also reduce muscle spindle sensitivity and passive stiffness, which can affect afferent feedback related to discomfort [31].

ROM restoration also indicates differences between recovery conditions. The SC group showed a greater increase in knee flexion ROM (Δ = +3.2 ± 1.6°; η^2 = 0.38) and higher adjusted post-recovery ROM than CON and SS. Static stretching alone was associated with smaller changes in ROM, consistent with previously reported viscoelastic adaptations [32]. The sequential application of stretching and massage may influence tissue mechanical responses during recovery. One possible explanation is that initial stretching temporarily reduces passive resistance, which may allow subsequent massage to act on tissues with lower stiffness.

One aspect of this study concerns the sequential organization of recovery modalities rather than their simple combination. The SC protocol progressed from controlled stretching counts (6–7–8 tempo) to varied manual techniques, concluding with effleurage. This sequence reflects the concept of viscoelastic priming followed by circulatory stimulation. From a mechanobiological perspective, tissue preconditioning through stretching may alter extracellular matrix stiffness and influence responsiveness to subsequent mechanical loading. Sequential mechanical stimuli may therefore interact with the mechanical properties of skeletal muscle and influence recovery-related processes [33]. However, mechanotransduction pathways were not directly assessed in the present study. Differences between SC and SM alone were smaller and were not consistently statistically significant, although effect sizes tended to favor SC. These findings suggest that massage contributes substantially to the observed recovery responses, while the addition of stretching may modify or support these effects.

Based on the analysis of previous research, recovery strategies in intermittent sports such as football are typically implemented within brief intervals between exercise bouts. These recovery periods, including halftime or short breaks during competition, usually last approximately 10–15 minutes and represent the practical timeframe within which early physiological restoration processes occur. The protocol applied in the present study was designed to reflect this type of recovery interval and to examine how different recovery modalities may influence short-term post-exercise responses.

The observed differences between recovery conditions indicate that the sequencing of stretching followed by massage may influence physiological and perceptual responses during this limited recovery window. These findings suggest that the organization and order of recovery interventions can affect how athletes respond during early recovery following high-intensity exercise. In practical settings, such structured combinations of recovery methods may therefore represent a feasible strategy for managing short-term recovery between bouts of intense activity in competitive sport environments.

Limitations of the Study

Several methodological aspects of the study should be considered when interpreting the findings.

The experimental protocol examined recovery responses within a single laboratory session following an acute bout of exercise. This design does not allow evaluation of delayed responses such as muscle damage or inflammatory dynamics over the subsequent 24–72 hours, nor cumulative recovery effects across repeated training sessions or matches.

The study employed a laboratory-based treadmill protocol to induce physiological stress. Although this model provides controlled and reproducible conditions, it may not fully replicate the biomechanical and tactical demands of match play in intermittent sports.

Interpretation of physiological mechanisms is also limited by the selected outcome variables. The analysis included lactate, IL-6, CK, perceived muscle pain, and range of motion. Other physiological processes involved in recovery, such as autonomic regulation, muscle oxygenation, or local perfusion, were not directly assessed.

Manual recovery techniques may also involve therapist-dependent variability despite the use of standardized pressure and tempo procedures.

Conclusions

A sequenced combination of stretching followed by massage was associated with improved short-term recovery responses compared with passive rest and single-modality interventions after high-intensity exercise. The findings indicate that organizing recovery modalities in a structured sequence may influence physiological and perceptual recovery during short post-exercise intervals. This approach may be considered when designing brief recovery protocols in intermittent sports.

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Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. Skorski S, Abbiss CR. The Manipulation of Pace within Endurance Sport. *Frontiers in Physiology*, 2017;8. https://doi.org/10.3389/fphys.2017.00102
2. Harris A, Gabbett TJ, King R, Bird SP, Terry P. Influence of Acute and Chronic Load on Perceived Wellbeing, Neuromuscular Performance, and Immune Function in Male Professional Football Players. *Sports*, 2025;13(6): 176. https://doi.org/10.3390/sports13060176
3. Mohr M, Draganidis D, Chatzinikolaou A, Barbero-Álvarez JC, Castagna C, Douroudos I, et al. Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. *European Journal of Applied Physiology*, 2016;116(1): 179–193. https://doi.org/10.1007/s00421-015-3245-2
4. Peake JM, Neubauer O, Walsh NP, Simpson RJ. Recovery of the immune system after exercise. *Journal of Applied Physiology*, 2017;122(5): 1077–1087. https://doi.org/10.1152/japplphysiol.00622.2016
5. White GE, West SL, Caterini JE, Di Battista AP, Rhind SG, Wells GD. Massage Therapy Modulates Inflammatory Mediators Following Sprint Exercise in Healthy Male Athletes. *Journal of Functional Morphology and Kinesiology*, 2020;5(1): 9. https://doi.org/10.3390/jfmk5010009
6. Crane JD, Ogborn DI, Cupido C, Melov S, Hubbard A, Bourgeois JM, et al. Massage Therapy Attenuates Inflammatory Signaling After Exercise-Induced Muscle Damage. *Science Translational Medicine*, 2012;4(119). https://doi.org/10.1126/scitranslmed.3002882
7. Waters-Banker C, Butterfield TA, Dupont-Versteegden EE. Immunomodulatory effects of massage on nonperturbed skeletal muscle in rats. *Journal of Applied Physiology*, 2014;116(2): 164–175. https://doi.org/10.1152/japplphysiol.00573.2013
8. Schroeder AN, Best TM. Is Self Myofascial Release an Effective Preexercise and Recovery Strategy? A Literature Review: *Current Sports Medicine Reports*, 2015;14(3): 200–208. https://doi.org/10.1249/JSR.0000000000000148
9. Davis HL, Alabed S, Chico TJA. Effect of sports massage on performance and recovery: a systematic review and meta-analysis. *BMJ Open Sport & Exercise Medicine*, 2020;6(1): e000614. https://doi.org/10.1136/bmjsem-2019-000614
10. Behm DG, Blazevich AJ, Kay AD, McHugh M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied Physiology, Nutrition, and Metabolism*, 2016;41(1): 1–11. https://doi.org/10.1139/apnm-2015-0235
11. Konrad A, Alizadeh S, Daneshjoo A, Anvar

SH, Graham A, Zahiri A, et al. Chronic effects of stretching on range of motion with consideration of potential moderating variables: A systematic review with meta-analysis. *Journal of Sport and Health Science*, 2024;13(2): 186–194. https://doi.org/10.1016/j.jshs.2023.06.002
12. Zhang P, Chen J, Xing T. Effects of post-exercise stretching versus no stretching on lower limb muscle recovery and performance: a meta-analysis. *Frontiers in Physiology*, 2025;16: 1674871. https://doi.org/10.3389/fphys.2025.1674871
13. Chaudhuri O, Cooper-White J, Janmey PA, Mooney DJ, Shenoy VB. Effects of extracellular matrix viscoelasticity on cellular behaviour. *Nature*, 2020;584(7822): 535–546. https://doi.org/10.1038/s41586-020-2612-2
14. Franklin NC, Ali MM, Robinson AT, Norkeviciute E, Phillips SA. Massage Therapy Restores Peripheral Vascular Function After Exertion. *Archives of Physical Medicine and Rehabilitation*, 2014;95(6): 1127–1134. https://doi.org/10.1016/j.apmr.2014.02.007
15. Fajar MK, Hariyanto A, Wahjuni ES, Kartiko DC, Siantoro G, Phanpheng Y, et al. Determining the Efficacy of Providing Ice Compression for Fitness Enhancement After Speed Endurance Exercise on Reducing Heart Rate, IL-6, and Fatigue Index in Football Athletes. *Physical Education Theory and Methodology*, 2025;25(1): 58–65. https://doi.org/10.17309/tmfv.2025.1.07
16. Rusdiawan A, Widodo A, Lani A, Özman C, Putra AY, Susanto N, et al. The Impact of Ice Compression and Massage Techniques on Lactate Removal and Interleukin-6 Concentrations During Halftime Recovery in Intermittent Sports. *Physical Education Theory and Methodology*, 2025;25(5): 1033–1041. https://doi.org/10.17309/tmfv.2025.5.01
17. Duncombe SL, Stylianou M, Price L, Walker JL, Barker AR. Making a HIIT: Methods for quantifying intensity in high-intensity interval training in schools and validity of session rating of perceived exertion. *Journal of Sports Sciences*, 2023;41(18): 1678–1686. https://doi.org/10.1080/02640414.2023.2291736
18. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? *Frontiers in Physiology*, 2014;5. https://doi.org/10.3389/fphys.2014.00073
19. Crotty NM, Boland M, Mahony N, Donne B, Fleming N. Reliability and Validity of the Lactate Pro 2 Analyzer. *Measurement in Physical Education and Exercise Science*, 2021;25(3): 202–211. https://doi.org/10.1080/1091367X.2020.1865966
20. Steensberg A, Van Hall G, Osada T, Sacchetti M, Saltin B, Pedersen BK. Production of interleukin-6 in contracting human skeletal muscles can account for the exercise-induced increase in plasma interleukin-6. *The Journal of Physiology*, 2000;529(1): 237–242. https://doi.org/10.1111/j.1469-7793.2000.00237.x
21. Yparraguirre Salcedo KG, Rivera Prado AB, Lloja Lozano L, Chambilla Quispe VF, Ramirez Atencio CW. Evaluating Muscle Damage Biomarkers in Adolescent Athletes: Implications for Public Health in Tacna, Peru—2023. *International Journal of Environmental Research and Public Health*, 2024;21(11): 1394. https://doi.org/10.3390/ijerph21111394
22. Pérez-Castillo ÍM, Rueda R, Bouzamondo H, López-Chicharro J, Mihic N. Biomarkers of post-match recovery in semi-professional and professional football (soccer). *Frontiers in Physiology*, 2023;14: 1167449. https://doi.org/10.3389/fphys.2023.1167449
23. Koo M, Yang SW. Visual Analogue Scale. *Encyclopedia*, 2025;5(4): 190. https://doi.org/10.3390/encyclopedia5040190
24. Hanks J, Myers B. Validity, Reliability, and Efficiency of a Standard Goniometer, Medical Inclinometer, and Builder's Inclinometer. *International Journal of Sports Physical Therapy*, 2023;18(4). https://doi.org/10.26603/001c.83944
25. Katoch R, Farooque S, Dhar K, Das PK. Effectiveness of two different recovery process on blood lactate removal pattern of soccer players. *Pedagogy of Physical Culture and Sports*, 2025;29(1): 62–67. https://doi.org/10.15561/26649837.2025.0107
26. Weerapong P, Hume PA, Kolt GS. The Mechanisms of Massage and Effects on Performance, Muscle Recovery and Injury Prevention: *Sports Medicine*, 2005;35(3): 235–256. https://doi.org/10.2165/00007256-200535030-00004
27. Scheller J, Chalaris A, Schmidt-Arras D, Rose-John S. The pro- and anti-inflammatory properties of the cytokine interleukin-6. *Biochimica et Biophysica Acta (BBA) - Molecular Cell Research*, 2011;1813(5): 878–888. https://doi.org/10.1016/j.bbamcr.2011.01.034
28. Nash D, Hughes MG, Butcher L, Aicheler R, Smith P, Cullen T, et al. IL -6 signaling in acute exercise and chronic training: Potential consequences for health and athletic performance. *Scandinavian Journal of Medicine & Science in Sports*, 2023;33(1): 4–19. https://doi.org/10.1111/sms.14241
29. Anderson AW, Soncini A, Lyons K, Hanney WJ. The Effect of Myofascial Stretching on Mechanical Nociception and Contributing Neural Mechanisms. *NeuroSci*, 2024;5(2): 158–168. https://doi.org/10.3390/neurosci5020011
30. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: A comprehensive model. *Manual Therapy*, 2009;14(5): 531–538. https://doi.org/10.1016/j.math.2008.09.001
31. Saito A, Mizuno T. Effect of static stretching duration on modulation of H-reflex and tendon-reflex excitability of the soleus muscle in young men. *Physiological Reports*, 2025;13(16): e70538. https://doi.org/10.14814/phy2.70538
32. Panidi I, Donti O, Konrad A, Dinas PC, Terzis G, Mouratidis A, et al. Muscle Architecture Adaptations to Static Stretching Training: A Systematic Review with Meta-Analysis. *Sports Medicine - Open*, 2023;9(1): 47. https://doi.org/10.1186/s40798-023-00591-7
33. Tiskratok W, Chuinsiri N, Limraksasin P, Kyawsoewin M, Jitprasertwong P. Extracellular Matrix Stiffness: Mechanotransduction and Mechanobiological Response-Driven Strategies for Biomedical Applications Targeting Fibroblast Inflammation. *Polymers*, 2025;17(6): 822. https://doi.org/10.3390/polym17060822

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ORIGINAL ARTICLE

Analysis of the dynamics of non-reactive agility under the influence of various structures (ladder and cones) in university students: a longitudinal study

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Abstract

Background and Study Aim: Agility is a component associated with skill-related fitness in physical activity. It is required in tasks that involve rapid changes in movement direction. Although various exercise methods are used to develop this ability, their application in university physical education remains a subject of practical interest. The purpose of the research is to design, implement, and verify the utility of a non-reactive agility development programme for university students with non-sports specialization.

Material and Methods: The study employed a single-group repeated-measures design with three assessment points: pretest, mid-test, and post-test. The investigated group consists of 572 subjects (315 males and 257 females) from the 1st and 2nd undergraduate years. The average duration of applying the exercises using ladders and cones was 20–25 minutes (8–10 minutes for ladders and 12–15 minutes for cones). Two structures from each category were used in most lessons. The heterogeneity of the students' physical preparation required differentiation of the demands and data analysis. Physically active subjects had longer routes, a greater number of sets, and more repetitions of the exercises, with shorter breaks compared to sedentary subjects. Nine non-reactive agility tests were applied (Hexagon, Fan test, T test, Illinois/primary outcome, 5–10–5 Pro-Agility, Edgren, 10 × 5 m Shuttle, Compass Drill, and Box Drill).

Results: The F values for repeated-measures ANOVA and χ^2 values for the Friedman test correspond to statistically significant thresholds ($p<0.05$) for most tests. The η^2p and Kendall's W results indicate very strong effects of the proposed experimental programme. The exceptions are the weak effects for sedentary males in the T test ($\eta^2p=0.031$) and Compass Drill ($\eta^2p=0.055$). Moderate effects were observed for physically active males in the Hexagon test ($\eta^2p=0.061$), Fan test ($\eta^2p=0.115$), and Illinois test ($\eta^2p=0.130$). The differences between the data pairs according to the three test moments indicate a significant improvement in performance ($p<0.05$) between the initial testing (T1) and the final testing (T3) for both genders and levels of physical activity in all agility tests. Some isolated insignificant differences ($p>0.05$) are reported between the initial testing (T1) and the intermediate testing (T2), and between the intermediate testing (T2) and the final testing (T3) (for example, the Edgren test for physically active females, and the T test and Compass Drill for sedentary males).

Conclusions: Statistical indicators confirm the usefulness of the experimental programme proposed to university students. The programme aims to improve non-reactive agility indicators for both genders and levels of physical activity. The use of diversified exercise structures based on ladders and cones increases the level of student involvement in the lesson. It also facilitates significant progress throughout the academic year for most of the applied tests. The results obtained are similar to those reported in other investigations on university students, but they are obviously lower compared to performance athletes of the same age range.

Keywords: non-reactive agility, university students, ladder and cone exercises, utility, physical education

Introduction

The development of motor abilities is a component of physical education programmes for university students. Among these abilities, agility reflects the capacity to perform rapid and controlled changes of direction during movement. This capacity depends on the interaction of several physical and coordination factors, including speed, balance, and movement control. The level of agility influences the execution of tasks that require quick transitions between movement directions and stable body control.

Change of Direction Speed (CODS or non-reactive agility) is associated with sports performance. Analysis of studies that investigated over 30,000 athletes from 12 different sports (team sports and

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individual sports) indicates higher results for subjects classified as elite level compared with beginners and sub-elite athletes, who show similar performances [1]. Agility is related to the performance of athletes in team games. Those classified as higher level are approximately 7.5% faster than those classified as lower level. Perceptual skills and speed of decision-making contribute to differences between players. Even though the reliability level for agility tests is generally good, this aspect may vary at younger ages [2]. Many team games and field sports involve changes in movement speed and multiple changes of direction to solve tasks. Analysis of the results for CODS and reactive agility (change of direction to stimuli), tested on the same route with four changes of direction (Hungarian football players from leagues 3 and 4, age 24.1 years), indicates better results for the CODS route. The correlation between the two tests is weak and insignificant. This indicates that reactive agility is conditioned by cognitive factors, and different strategies are required for the development and testing of this skill [3]. Developing agility (as a factor involving speed, balance, and coordination) at the level of primary school students creates opportunities to identify and guide students who show higher results in these tests towards practicing various sports games [4].

CODS is particularly associated with muscle strength values, whereas reactive agility (RAG) is also associated with and depends on the cognitive abilities of the test subjects. The evaluation of the two forms of agility in groups of Bosnian children in the pubertal stage (14.86 years) indicates differences between genders. Boys rely mainly on strength gains, whereas girls rely more on cognitive abilities [5]. Recent investigations on Italian amateur university athletes (football, volleyball, martial arts, swimming) have determined associations between explosive strength, reactive strength, and agility. All these complex psychophysical abilities are decisive in achieving sports performance [6]. Other studies address the importance of muscle strength and agility in volleyball and handball [7, 8, 9], or the variations determined by body composition [10]. Another study conducted on Croatian pubertal students found that cognitive abilities cannot be considered a good predictor of reactive agility. In contrast, speed and muscle strength are strongly associated with the values of non-reactive agility tests, especially for boys with above-average motor development. CODS is a good predictor of reactive agility, especially for girls [5]. Similarly, recent research on early pubertal children showed that anthropometric characteristics are weakly related to reactive agility performance, whereas motor abilities such as change of direction speed and explosive leg power significantly contribute to the prediction of reactive agility in both boys and girls [11]. Strong associations between CODS and acceleration capacity over distances of 10–30 m, explosive strength, and reactive power of leg muscles (jumping ability) are analyzed in [12]. It is recommended to choose agility tests according to the requirements of the sport played. The tests should reflect the specific movement variants, total distances, and changes of direction characteristic of these activities.

Other factors that should be taken into account are gender differences, body mass index, and years of practice [12]. Testing young football and handball players (12–13 years, pubertal stage) with the T and Illinois tests supports their superior reliability in measuring agility. These variants are also good indicators for measuring sprinting ability and jumping ability (muscle power). These abilities can be approached as similar motor skills for athletes involved in these sports games [13]. Investigations on university students with sports specialization and football players of similar age indicate better values for football players in reactive and non-reactive agility tests. Males also have significantly better results than females, especially for reactive agility. These values indicate the need for separate assessment and diagnosis of agility according to gender and through exercises or structures specific to each sport [14]. Another factor influencing the results of CODS tests is the quality of running technique. Technique optimization (4 weeks × 2 sessions) facilitated significant improvements for young soccer players (U11, U13, and U18) in the Pro-Agility test (5-10-5) [15]. A study analyzing agility scores using the T-test for Junior Hapkido athletes in West Sumatra identified poorer values for both genders compared to national standards [16].

An analysis of investigations that addressed different training methods aimed at improving the ability to CODS indicates that the most effective solution is sprinting, followed by plyometric exercises, resistive training, and the combined application of these variants [17]. The integration of plyometric training in the training process of adolescent soccer players in Turkey (6 weeks) ensures a significant increase in performance for lower limb muscle strength (vertical jump variants) and for non-tactile agility (T-test). However, no significant differences were reported between the control group and the experimental group for 30 m acceleration [18]. Plyometric programmes applied in the training of Belgian adolescents practicing recreational basketball (4–8 weeks) have positive effects on vertical jump (CMJ) values and agility. The use of specially designed footwear (elevated forefoot platforms that keep the heels on the ground) provides a superior increase in performance compared to the use of regular sports shoes [19]. Other studies focus on optimizing coordination processes and motor skills in sports games (rugby and soccer), where agility is important [20, 21].

Another investigation notes the beneficial effect of Small Sided and Conditioning Games (SSG) in increasing agility results, aerobic capacity, and anaerobic power. Better effects related to technical-tactical skills are also reported. The use of these exercises in the training of futsal players (18.6 years) has similar effects to the traditional generic fitness training (GFT) version [22]. For young female soccer players at the high school level in Nigeria, the use of a training programme aimed at optimizing fitness indicators (12 weeks × 3 sessions) significantly increases agility (Illinois test) performance and aerobic capacity, but not leg strength values [23]. Other researchers recommend the use of exercises based on the BlazePod device (6 weeks × 3 sessions × 90 minutes) as a solution for increasing agility and reaction speed performance in female handball players [24]. Recent studies emphasize the use of CODS tests, especially those of reactive agility (based on stops, accelerations, and decelerations at light signals). Their advantage is related to the differentiation of athletes of different levels and age stages, and to the predictive nature regarding potential injuries [25].

Exercises based on eccentric contractions have positive effects on improving performance in agility tests. In football, basketball, hockey, and handball, the eccentric variant is involved in the braking phase of movements and in increasing performance in the speed of changing direction [26]. Lateral movements, agility, and acceleration capacity are priority skills for primary school students (10 years). The implementation of special exercise programmes (6 months) for these qualities ensured significant progress in performance in six classic non-reactive agility tests [27]. The implementation of programmes based on coordination and agility exercises facilitates the improvement of nine specific fencing skills for Iraqi students. The progress is explained by the general adaptation syndrome theory (GAS). Physiological demands force the muscles to adapt to new tasks and increase motor performance [28]. The rapidity of badminton-specific actions requires special training. The use of combined exercises using plyometrics and ladder drills ensures the optimization of agility (T-test), explosive leg strength, and speed for young badminton players (12–16 years) in Indonesia [29]. For visually impaired goalball athletes in Thailand, the development of agility is facilitated by using a smart ladder drill prototype, with training planned for 8 weeks. Significant differences are found between the initial and final testing. For agility exercises, distances of 5–10 m and movements between three and five targets are recommended [30]. The combination of short-distance accelerations and structures based on zig-zag movements is effective for performance in speed and agility tests for Indonesian students [31]. Developing agility through Speed, Agility, Quickness (SAQ) training is more effective than using traditional methods. The application of this solution for eight weeks in Chinese university students is characterized by attractiveness, flexibility, and multilateral effects. Significant progress was noted in the ability to change direction [32].

Analysis of research findings has shown that agility and change-of-direction speed are associated with multiple physical and coordination factors and are influenced by different types of training methods and exercise structures. Researchers emphasize that agility performance depends on the interaction of speed, strength, balance, coordination, and cognitive processes involved in movement control and decision-making. At the same time, the practical application of agility-oriented exercise structures in the context of university physical education requires consideration of the characteristics of students with non-sports specialization and the conditions of regular educational activities. These aspects create a context for analyzing the effectiveness of structured exercise programmes aimed at developing non-reactive agility within university physical education. Most investigations address the development of non-reactive agility through various training programmes with a priority orientation towards performance sports. However, in university physical education the successful involvement of students in lesson activities that require rapid changes of direction is associated with the level of agility indicators. The purpose of the research is to design, implement, and verify the utility of a non-reactive agility development programme for university students with non-sports specialization. It is estimated that the application of this experimental programme will lead to an improvement in non-reactive agility indicators during an academic year.

Materials and Methods

Participants

The study initially included 603 university students with non-sports specialization from the 1st and 2nd undergraduate years of study. The subjects were recruited through randomized cluster selection (different study programmes): Medicine, Dental Medicine, Computers and Automation, Electrical and Electronic Engineering, History and Philosophy, Public Administration, Sciences and Environment, Economics, and Business Administration. Students who did not participate in all non-reactive agility assessment tests, those who did not participate in at least 85% of the scheduled teaching activities, or those who, for various reasons, withdrew from the study (31 cases) were not included in the statistical analysis of the data. A total of 572 subjects (315 males and 257 females) remained for the processing of the obtained data. Most students who did not

meet the lesson engagement criterion (⩾85%) were also absent from one or more evaluation moments. The results collected from these cases were eliminated from the statistical analysis. Each gender was analyzed according to the level of involvement in physical activities (physically active students involved in physical activities at least three times a week versus sedentary students). The sample size was calculated with G*Power 3.1.9.7 for Windows (f=0.25, 1-β=0.95, α=0.05). The calculation indicated a minimum of 44 subjects for each gender. The studied groups numerically exceeded this determined threshold. All students were informed about the purpose of the study. Informed consent for participation was obtained. The requirements for investigations involving human subjects according to the Declaration of Helsinki [33] were respected. The study received approval from the Ethics Committee of the educational institution (No. 134/18.04.2024).

Table 1 summarizes the main characteristics of the investigated group. It should be noted that the number of physically active females compared to sedentary females is very small. Only one in ten studied females is physically active. In comparison, one in three studied males is physically active.

Research Design

The study employed a single-group repeated-measures design with three assessment points: pretest, mid-test, and post-test. The research was conducted in the 2023–2024 academic year. Nine non-reactive agility tests were applied (Hexagon, Fan test, T test, Illinois, 5–10–5 Pro-Agility, Edgren, 10×5 m Shuttle, Compass Drill, and Box Drill). Testing was repeated three times: in weeks 1, 12, and 27.

Given the complex nature of agility, the Illinois Agility Test was designated as the primary outcome of the study. This choice is based on its high representativeness and its extensive use in the international literature. The Illinois test was considered the most appropriate for evaluating the overall impact of the intervention programme. It integrates a wide range of specific demands: explosive accelerations, controlled decelerations, meandering running (slalom), and changes of direction at different angles.

The other agility tests were treated as secondary outcomes. Their role was to provide a detailed perspective on the specific components of agility (segmental coordination, lateral speed, and dynamic balance).

1.Hexagon Test.

The test assesses speed, agility, and the athlete's ability to start, stop, and maintain balance during rapid movements over short distances with departures and returns in all directions. The hexagon consists of six sides, each measuring 60.5 cm. The athlete jumps from the center of the hexagon to the outside of each side and immediately returns to the starting position after each jump. The direction of rotation can be chosen by the subject. Landing on the lines is not allowed. Three complete cycles are performed, which corresponds to 18 round-trip jumps [34].

2.T Agility Test.

The tested subject runs along a T-shaped route marked by four cones (A, B, C, D). The movement

Table 1. Descriptive statistics for the tested groups (male sedentary = 210, male active = 105, female sedentary = 236, female active = 21).

Variables	Gender	Group type	Minimum	Maximum	Mean	Std. Deviation	Std. Error
Age	Male	sedentary	19	35	20.809	3.041	0.209
		active	19	30	20.383	2.112	0.206
	Female	sedentary	18	32	21.103	3.199	0.208
		active	18	25	20.728	1.767	0.386
Weight	Male	sedentary	45.00	128.00	77.824	16.129	1.113
		active	49.00	104.00	74.619	11.904	1.162
	Female	sedentary	38.00	105.00	61.275	12.051	0.784
		active	43.00	75.00	59.523	8.812	0.386
Height	Male	sedentary	156.00	200.00	179.171	7.407	0.511
		active	143.00	197.00	178.257	8.434	0.823
	Female	sedentary	150.00	181.00	164.631	6.282	0.409
		active	158.00	182.00	168.381	6.289	1.372
BMI	Male	sedentary	15.40	41.50	24.151	4.511	0.311
		active	15.50	38.20	23.527	3.794	0.370
	Female	sedentary	14.00	40.00	22.534	4.253	0.277
		active	16.20	26.35	20.976	2.804	0.612

sequence is as follows: from A to B while touching cone B, from B to C while touching cone C, from C to D while touching cone D, returning to C, and then moving backward to A. On the segment B–C–D–B the movement is performed with lateral steps. One yard equals 0.9144 m. Excellent results are considered to be less than 9.5 s for males and less than 10.5 s for females [34].

3.Illinois Agility Test.

The participant runs a course consisting of eight markers, including slalom movement between the central markers. The test begins from a prone or squat starting position. The participant runs the prescribed route as quickly as possible. An excellent score is considered to be under 15.2 seconds for males and under 17 seconds for females [34].

4.5-10-5 Pro-Agility Test (5-10-5 Shuttle).

The participant runs along a course marked by three parallel lines positioned 5 yards apart (right, center, and left). The sequence of movement is as follows: sprint 5 yards to the right, sprint 10 yards to the left, and then sprint 5 yards back to the center line. During each change of direction, the athlete must touch the line with the foot [34].

5.Edgren Side Step Test.

Five cones or floor markers are placed 1 m apart, creating a 4 m route for one full movement. The participant starts at the center marker and performs lateral movements to the right until the last cone, which must be passed with the outside foot. The participant then moves laterally to the opposite side. The movement continues for 10 seconds. The number of correctly passed cones or the distance covered in meters is recorded. Crossing the legs is not allowed and the torso must remain facing forward [34].

6.10 × 5 m Shuttle Test.

Two parallel lines marked by cones are placed 5 m apart. The participant starts with one foot behind the starting line and runs back and forth between the lines ten times (five round trips). Each turn requires crossing the line with both feet. The total distance covered is 50 m [34].

7.Compass Drill (Agility Cone Drill Test).

Five cones are arranged in the pattern of the cardinal points of a compass. Cone 1 is placed in the center, while cones 2–5 are positioned 3 m from the central cone. The participant starts next to the central cone facing cone 5. At the signal, the participant moves to cone 2 and returns to cone 1, then to cone 3 and back, then to cone 4 and back, and finally sprints to cone 5 to finish. The route is repeated in the opposite direction after a three-minute break. The two results are averaged. The cones must be touched with the hand at each movement [34].

8.Box Drill Fitness Test.

Participants run a square-shaped course marked by four cones. The side of the square measures 10 yards. The starting point coincides with the finish line. Movement is performed along the outer sides of the square: side 1 sprint forward, side 2 lateral movement, side 3 backward movement, and side 4 sprint forward to the finish [34].

9.Evantai Test (Romanian Tennis Federation) [35].

The test evaluates tennis-specific movement speed, coordination, and the ability to accelerate and decelerate over short distances in multiple directions. The athlete must sprint to collect and place five balls positioned on the tennis court at the starting point. Movement may be performed facing the running direction during both the outward and return phases, except after collecting ball number three, when the movement must be performed backward toward the deposit point. The tennis court dimensions used in the test are: court width between points 1–5 equal to 8.23 m and rectangle length between points 1–2 or 4–5 equal to 5.485 m.

The activities aimed at influencing the ability to change direction were planned within the facilities of the Faculty of Physical Education and Sports in Galați. They were applied in each lesson immediately after the warm-up session. The frequency of applying agility exercises was one session per week. The average duration of exercises using ladders and cones was 20–25 minutes (8–10 minutes for ladders and 12–15 minutes for cones). Two structures from each category were used in most lessons. The exercise planning and the approximate duration of the recovery breaks between sets and repetitions are presented in Table 2. The intensity of the exercises was 75–95%. The emphasis during execution was placed on a low body position and good movement control. Feedback was provided to correct technique and prevent injuries. The exercises were changed or diversified from one lesson to another to provide new stimuli and increase attractiveness. The distances used for the ladder exercises were 8–15 m, and for the cone structures 10–25 m. The heterogeneity of the physical preparation of the students required differentiation of the demands. Physically active subjects had longer routes and a greater number of sets and repetitions of the exercises, with shorter breaks compared to sedentary subjects. The dosages presented in the tables are indicative for the average fitness level of the participants. The values may increase or decrease depending on the perceived level of effort (RPE, Rate of Perceived Exertion).

Statistical Analysis

The statistical calculation of the recorded data was based on the application of parametric ANOVA tests with repeated measures, conducted separately by gender and level of physical activity. The sphericity conditions were met in few cases. As

Table 2. Annual Agility Program (20-25 minutes/lesson)

Week	Ladder drills exercises	Dosage Ladder (S x R)	Recovery (rep; set)	Cone drills exercises	Dosage Cone drills (S × R)	Recovery (between repetitions; between sets)
1.	**Testing 1/Initial - October**					
2.	Forward step + Sidestep	2 x 3	30''; 60''	5x5 m square + Triangle	2 x 3	30''; 60''
3.	Bunny hops + Forward step	2 x 3	30''; 60''	Triangle + 5x5 m square	2 x 3	30''; 60''
4.	Sidestep + Side run	2 x 3	30''; 60''	X drill + L drill	2 x 3	30''; 60''
5.	Forward + Straddle hops	2 x 3	30''; 60''	Triangle + Zig-zag	2 x 3	30''; 60''
6.	Side run + In and out	2 x 3	30''; 60''	X drill + Sprint 45° cut	2 x 3	30''; 60''
7.	Straddle hops + Forward step	2 x 3	30''; 60''	L drill + Y drill	2 x 3	30''; 60''
8.	In and out + Twist hops	2 x 3	30''; 60''	Zig-zag + I-of-pain drill	2 x 3	30''; 60''
9.	Side run + Ali shuffle	2 x 3	30''; 60''	Sprint 45° + Staggered shuttle	2 x 3	30''; 60''
10.	Twist hops + Bunny hops	2 x 3	30''; 60''	I-of-pain drill + Triangle	2 x 3	30''; 60''
11.	Ali shuffle + Sidestep	2 x 3	30''; 60''	Staggered shuttle + X drill	2 x 3	30''; 60''
12.	**Testing 2/Intermediate - December**					
13.	Twist hops + Ali shuffle	2 x 3	30–40''; 60''	I-of-pain drill + Cone Cone Alley v1	2 x 3	45''; 90''
14.	River dance + Ickey shuffle	2 x 3	30–40''; 60''	Two-track + W drill	2 x 3	60''; 90''
15.	River dance + Forward step	2 x 3	30–40''; 60''	W drill + Cone Cone Alley v1	2 x 3	40''; 75''
16.	Ickey shuffle + In and out	2 x 3	30–40''; 60''	Cone Cone Alley v1 + 1-2-3 back	2 x 3	45''; 90''
17.	River dance + Ickey shuffle	2 x 3	30–40''; 60''	1-2-3 back + Cone Alley v2	2 x 3	45''; 90''
18.	Ali shuffle + Bunny hops	2 x 3	30–40''; 60''	Cone Cone Alley v1 + Zig-zag	2 x 3	45''; 90''
19.	Forward step + In and out	2 x 3	30–40''; 60''	Cone Alley v2 + Run-shuffle-run	2 x 3	45''; 90''
20.	Ali shuffle + Ickey shuffle	2 x 3	30–40''; 60''	Zig-zag + L drill	2 x 3	45''; 90''
21.	Mix 3 exercises + Side run	2 x 3	30–40''; 60''	Cone Alley v2 + X drill	2 x 3	45''; 90''
22.	Bunny hops + Straddle hops	2 x 3	30–40''; 60''	Run-shuffle-run + Triangle	2 x 3	45''; 90''
23.	Sequence 3 exercises	2 x 3	40-45''; 60''	Circuit L drill + X drill	2 x 3	90''; 120''
24.	Mix 3 exercises	2 x 3	40-45''; 60''	Triangle + 1-2-3 back	2 x 3	90''; 120''
25.	Mix 4 exercises	2 x 3	40-45''; 60''	Cone Alley v1 + Shuttle	2 x 3	90''; 120''
26.	Complex circuit (4-5 ex.)	2 x 3	45-60''; 90''	Agility circuit (4structures)	2 x 3	120''; 120''
27.	**Testing 3/Final - May**					

a result, the Greenhouse-Geisser correction factor (for $\varepsilon < 0.75$) and Huynh-Feldt (for $\varepsilon > 0.75$) were applied. The results for the values of F, effect size (Partial Eta Squared, with control of other factors influencing the results), the values of Sig., Noncent. Parameter, and Obs. Power were synthesized in tables. The Bonferroni correction factor was applied in the comparison of pairs of results. The confidence interval was set at 95%. For the group of active females (N = 21), the non-parametric Friedman test was used, with the calculation of χ^2, Kendall's W, and Adj. Sig. (Bonferroni, $p = 0.0167$).

Results

Tables 3 and 4 summarize the main indicators resulting from the application of ANOVA with repeated measures, conducted separately by gender and categories of physical activity. It is observed that the F values correspond, in all cases, to statistical significance thresholds ($p < 0.05$). This confirms the usefulness of the motor structures used to improve agility indicators. However, the η^2p values indicate very weak effects in the case of sedentary students for the T test (male), where only 3.1% of the variance of the result is explained by the implemented programme, and for the Compass Drill (male), where

Table 3. Results of Mauchly's Test of Sphericity and ANOVA with repeated measures for agility tests (sedentary students: Male = 210, Female = 236)

Test	Group	Mauchly's Test		Correction factor	df	Error df	F	Sig.	η^2p	Noncent. Parameter	Obs. Power
		Sig.	ε								
Hexagon	Male	0.000	0.765	Huynh-Feldt	1.531	319.968	181.112	0.000	0.464	277.273	1.000
	Female	0.000	0.642	Greenhouse-Geisser	1.284	301.696	238.736	0.000	0.504	306.493	1.000
Fan test	Male	0.000	0.623	Greenhouse-Geisser	1.246	260.449	275.179	0.000	0.568	342.919	1.000
	Female	0.000	0.565	Greenhouse-Geisser	1.130	265.477	213.452	0.000	0.476	241.135	1.000
T test	Male	0.000	0.526	Greenhouse-Geisser	1.052	219.966	6.635	0.010	0.031	6.983	0.742
	Female	0.000	0.573	Greenhouse-Geisser	1.145	269.140	222.180	0.000	0.486	254.458	1.000
Illinois	Male	0.000	0.571	Greenhouse-Geisser	1.142	238.659	600.255	0.000	0.742	685.437	1.000
	Female	0.000	0.608	Greenhouse-Geisser	1.216	285.820	815.297	0.000	0.776	991.609	1.000
5–10–5 Pro-Agility	Male	0.000	0.675	Greenhouse-Geisser	1.350	282.075	65.338	0.000	0.238	88.183	1.000
	Female	0.000	0.701	Greenhouse-Geisser	1.403	329.667	698.382	0.000	0.748	979.714	1.000
Edgren	Male	0.000	0.927	Huynh-Feldt	1.855	387.686	366.637	0.000	0.637	680.096	1.000
	Female	0.076	0.987	Sphericity Assumed	2	470	318.997	0.000	0.576	637.994	1.000
10 × 5 m Shuttle	Male	0.000	0.709	Greenhouse-Geisser	1.417	296.161	184.409	0.000	0.469	261.314	1.000
	Female	0.010	0.971	Huynh-Feldt	1.942	456.294	2810.765	0.000	0.923	5457.592	1.000
Compass Drill	Male	0.000	0.587	Greenhouse-Geisser	1.174	245.262	12.119	0.000	0.055	14.222	0.958
	Female	0.000	0.619	Greenhouse-Geisser	1.238	291.041	717.795	0.000	0.753	888.970	1.000
Box Drill	Male	0.000	0.656	Greenhouse-Geisser	1.311	274.085	1307.932	0.000	0.862	1715.236	1.000
	Female	0.000	0.723	Greenhouse-Geisser	1.446	339.742	2383.522	0.000	0.910	3445.885	1.000

Table 4. Results of Mauchly's Test of Sphericity and ANOVA with repeated measures for agility tests (physically active students Male = 105, Female = 21)

Test	Group	Mauchly's Test		Correction factor	df	Error df	F	Sig.	η^2p	Noncent. Parameter	Obs. Power
		Sig.	ε								
Hexagon	Male	0.000	0.505	Greenhouse-Geisser	1.011	105.099	6.722	0.011	0.061	6.793	0.732
	Female	0.000	0.508	Greenhouse-Geisser	1.016	20.324	12.641	0.002	0.387	12.846	0.925
Fan test	Male	0.000	0.511	Greenhouse-Geisser	1.022	106.294	13.452	0.000	0.115	13.749	0.956
	Female	0.000	0.627	Greenhouse-Geisser	1.253	25.064	272.261	0.000	0.932	341.198	1.000
T test	Male	0.000	0.793	Huynh-Feldt	1.586	164.930	1407.859	0.000	0.931	2232.682	1.000
	Female	0.025	0.805	Huynh-Feldt	1.611	32.213	290.929	0.000	0.936	468.578	1.000
Illinois	Male	0.000	0.507	Greenhouse-Geisser	1.015	105.508	15.548	0.000	0.130	15.774	0.975
	Female	0.733	1.000	Sphericity Assumed	2	40	586.410	0.000	0.967	1172.820	1.000
5–10–5 Pro-Agility	Male	0.606	1.000	Sphericity Assumed	2	208	388.258	0.000	0.789	776.516	1.000
	Female	0.100	0.887	Huynh-Feldt	1.774	35.478	139.117	0.000	0.874	246.780	1.000
Edgren	Male	0.153	0.983	Sphericity Assumed	2	208	123.932	0.000	0.544	247.863	1.000
	Female	0.710	1.000	Sphericity Assumed	2	40	20.240	0.000	0.503	40.479	1.000
10 × 5 m Shuttle	Male	0.000	0.699	Greenhouse-Geisser	1.398	145.381	1189.665	0.000	0.920	1663.023	1.000
	Female	0.001	0.665	Greenhouse-Geisser	1.330	26.597	96.842	0.000	0.829	128.785	1.000
Compass Drill	Male	0.000	0.884	Huynh-Feldt	1.769	183.962	890.093	0.000	0.895	1574.455	1.000
	Female	0.000	0.533	Greenhouse-Geisser	1.067	21.335	9.425	0.005	0.320	10.054	0.849
Box Drill	Male	0.000	0.684	Greenhouse-Geisser	1.368	142.236	1042.38	0.000	0.909	1425.620	1.000
	Female	0.312	0.979	Sphericity Assumed	2	40	292.268	0.000	0.936	584.535	1.000

the explained variance is only 5.5%. In the other cases, all values are above the threshold of 0.14. This indicates very strong effects for the applied tests. For example, Box Drill (female) explains 91% of the variance, Box Drill (male) explains 86.2% of the variance, and 10 × 5 m Shuttle (female) explains 92.3% of the variance. For students in the physically active category, the η^2p values indicate moderate effects only in three situations: Hexagon (male) with 6.1% of the variance, Fan test (male) with 11.5% of the variance, and Illinois (male) with 13% of the explained variance. The other values confirm very strong effects of the experimental programme. For example, Illinois (female) explains 96.7% of the variance, Fan test (female) explains 93.2% of the variance, 10 × 5 m Shuttle (male) explains 92% of the variance, and T test (male) explains 93.1% of the variance. The high values of the Noncent. Parameter for most of the applied tests indicate that the proposed agility programme has clear, strong, and detectable effects on the obtained results. Obs. Power scores indicate, in most situations, values above the threshold of 0.8. This means that there is a probability of over 80% of detecting significant improvements in agility performance. It also indicates correct detection of differences between the three applied test moments and reduced risks of committing a Type II statistical error.

Tables 5 and 6 present the dynamics of performance in agility tests and the comparison of the significance of differences across data points for sedentary students. For males, significant performance improvements are identified in most situations. However, two exceptions were identified.

Table 5. Average results and pairwise differences for the three agility assessments (sedentary males, N = 210)

Test	Mean	SE	T1-T2	Sig.b	T2-T3	Sig.b	T1-T3	Sig.b	95% CI		d
									Lower	Upper	
Hexagon T1	16.530	0.174									
Hexagon T2	16.466	0.173	0.064*	0.000	0.076*	0.000	0.140*	0.000	0.121	0.157	1.069
Hexagon T3	16.390	0.172									
Fan test T1	20.212	0.148									
Fan test T2	20.138	0.149	0.074*	0.000	0.065*	0.000	0.139*	0.000	0.133	0.144	3.412
Fan test T3	20.073	0.148									
T test T1	12.549	0.098									
T test T2	12.541	0.103	0.008	1.000	0.083*	0.045	0.091*	0.000	0.078	0.103	1.001
T test T3	12.458	0.098									
Illinois T1	19.613	0.124									
Illinois T2	19.541	0.123	0.072*	0.000	0.077*	0.000	0.149*	0.000	0.138	0.159	1.963
Illinois T3	19.463	0.123									
5–10–5 Pro-Agility T1	6.262	0.038									
5–10–5 Pro-Agility T2	6.243	0.038	0.019*	0.000	0.034*	0.000	0.053*	0.000	0.042	0.064	0.657
5–10–5 Pro-Agility T3	6.209	0.039									
Edgren T1	16.076	0.146									
Edgren T2	16.448	0.142	-0.371*	0.000	-0.495*	0.000	-0.867*	0.000	-0.920	-0.813	2.205
Edgren T3	16.943	0.138									
10 × 5 m Shuttle T1	20.556	0.116									
10 × 5 m Shuttle T2	20.487	0.116	0.069*	0.000	0.082*	0.000	0.151*	0.000	0.134	0.167	1.244
10 × 5 m Shuttle T3	20.405	0.115									
Compass Drill T1	7.831	0.071									
Compass Drill T2	7.794	0.073	0.037*	0.029	0.023	0.384	0.061*	0.000	0.050	0.070	0.824
Compass Drill T3	7.770	0.070									
Box Drill T1	12.587	0.111									
Box Drill T2	12.542	0.111	0.045*	0.000	0.048*	0.000	0.093*	0.000	0.088	0.097	2.831
Box Drill T3	12.494	0.110									

Note. * - The mean difference is significant at the 0.05 level; b - Adjustment for multiple comparisons: Bonferroni.

Table 6. Average results and pairwise differences for the three agility assessments (Sedentary females, N=236)

Test	Mean	SE	T1-T2	Sig.b	T2-T3	Sig.b	T1-T3	Sig.b	95% CI		d
									Lower	Upper	
Hexagon T1	17.563	0.152									
Hexagon T2	17.510	0.153	0.053*	0.000	0.071*	0.000	0.124*	0.000	0.110	0.137	1.156
Hexagon T3	17.439	0.153									
Fan test T1	22.358	0.128									
Fan test T2	22.282	0.127	0.076*	0.000	0.072*	0.000	0.147*	0.000	0.142	0.152	3.786
Fan test T3	22.210	0.128									
T test T1	14.329	0.086									
T test T2	14.289	0.086	0.040*	0.000	0.044*	0.000	0.084*	0.000	0.074	0.093	1.167
T test T3	14.245	0.085									
Illinois T1	21.993	0.109									
Illinois T2	21.915	0.109	0.078*	0.000	0.079*	0.000	0.157*	0.000	0.147	0.165	2.182
Illinois T3	21.836	0.108									
5–10–5 Pro-Agility T1	6.857	0.036									
5–10–5 Pro-Agility T2	6.835	0.037	0.021*	0.000	0.028*	0.000	0.049*	0.000	0.045	0.052	1.887
5–10–5 Pro-Agility T3	6.808	0.035									
Edgren T1	15.445	0.113									
Edgren T2	15.839	0.110	-0.394*	0.000	-0.398*	0.000	-0.792*	0.000	-0.849	-0.735	1.775
Edgren T3	16.237	0.107									
10 × 5 m Shuttle T1	22.322	0.102									
10 × 5 m Shuttle T2	22.252	0.101	0.070*	0.000	0.079*	0.000	0.149*	0.000	0.145	0.153	4.756
10 × 5 m Shuttle T3	22.172	0.102									
Compass Drill T1	8.762	0.064									
Compass Drill T2	8.735	0.065	0.027*	0.000	0.029*	0.000	0.056*	0.000	0.052	0.059	2.044
Compass Drill T3	8.707	0.064									
Box Drill T1	14.490	0.099									
Box Drill T2	14.441	0.099	0.048*	0.000	0.054*	0.000	0.102*	0.000	0.098	0.106	3.667
Box Drill T3	14.387	0.098									

Note. * - The mean difference is significant at the 0.05 level; b - Adjustment for multiple comparisons: Bonferroni.

The T test for semester 1 (T1–T2) indicates an insignificant improvement in the result ($p > 0.05$). The Compass Drill for semester 2 (T2–T3) also indicates an insignificant difference ($p > 0.05$). However, the differences between the initial and final tests (T1–T3) are significant even for these two cases ($p < 0.05$). Thus, the progress generated by the training programme throughout the entire academic year is statistically confirmed. For sedentary females, the results confirm the existence of significant progress during both semesters for all agility tests ($p < 0.05$). Therefore, there are no stagnations or insignificant differences as observed in the male group. The effect size values (Cohen's d) calculated for the T1–T3 pair are very large ($d > 0.8$) for both genders. This confirms the practical effect of the agility exercises used. The only exception was identified for the male group in the Pro-Agility test, where the d score indicates a medium effect size ($d = 0.657$).

Tables 7 and 8 present the dynamics of agility test performance and the comparison of the significance of differences across data sets for physically active students. Most of the compared data sets indicate significant differences. However, for the male group insignificant progress ($p > 0.05$) is reported in three situations: for the Hexagon and Fan test during semester 2 (T2–T3) and for the Illinois test during semester 1 (T1–T2). Cohen's d calculated for the T1–T3 pair indicates high effect size values ($d > 0.8$) for most tests in men. The only exception is the Hexagon test, where a weak value was identified ($d = 0.289$). At the level of the active female group (Table 8), the Friedman test indicates a significant difference between the three agility test moments.

Table 7. Average results and pairwise differences for the three agility assessments (Physically active males, N=105)

Test	Mean	SE	T1-T2	Sig.b	T2-T3	Sig.b	T1-T3	Sig.b	95% CI		d
									Lower	Upper	
Hexagon T1	14.171	0.178									
Hexagon T2	14.118	0.177	0.052*	0.000	0.033	0.744	0.086*	0.011	0.028	0.142	0.289
Hexagon T3	14.085	0.180									
Fan test T1	18.370	0.120									
Fan test T2	18.287	0.124	0.083*	0.016	0.037	0.597	0.120*	0.000	0.113	0.127	3.345
Fan test T3	18.250	0.118									
T test T1	11.315	0.074									
T test T2	11.277	0.074	0.038*	0.000	0.036*	0.000	0.074*	0.000	0.070	0.077	4.373
T test T3	11.241	0.073									
Illinois T1	18.359	0.122									
Illinois T2	18.326	0.122	0.033	0.764	0.093*	0.004	0.126*	0.000	0.120	0.131	4.297
Illinois T3	18.233	0.121									
5–10–5 Pro-Agility T1	5.774	0.033									
5–10–5 Pro-Agility T2	5.756	0.033	0.018*	0.000	0.024*	0.000	0.041*	0.000	0.038	0.044	2.750
5–10–5 Pro-Agility T3	5.733	0.034									
Edgren T1	17.705	0.175									
Edgren T2	17.990	0.163	-0.286*	0.000	-0.438*	0.000	-0.724*	0.000	-0.810	-0.636	1.611
Edgren T3	18.429	0.162									
10 × 5 m Shuttle T1	19.237	0.115									
10 × 5 m Shuttle T2	19.181	0.114	0.057*	0.000	0.061*	0.000	0.117*	0.000	0.111	0.123	3.721
10 × 5 m Shuttle T3	19.120	0.115									
Compass Drill T1	7.070	0.073									
Compass Drill T2	7.047	0.073	0.023*	0.000	0.025*	0.000	0.048*	0.000	0.045	0.050	3.602
Compass Drill T3	7.022	0.072									
Box Drill T1	11.234	0.086									
Box Drill T2	11.194	0.086	0.039*	0.000	0.041*	0.000	0.081*	0.000	0.076	0.085	3.519
Box Drill T3	11.153	0.085									

Note. * - The mean difference is significant at the 0.05 level; b - Adjustment for multiple comparisons: Bonferroni.

Table 8. Average results and pairwise differences for the three agility assessments - Friedman test (Physically active females, N=21)

Test	Mean	SE	χ^2 (df)	Asymp.Sig.	Kendall's W	Adj. Sig. T1-T2	Adj. Sig. T2-T3	Adj. Sig. T1-T3
Hexagon T1	15.140	0.507	42.000 (2)	0.000	1.000	0.004	0.004	0.000
Hexagon T2	15.093	0.507						
Hexagon T3	15.001	0.509						
Fan test T1	20.428	0.283	42.000 (2)	0.000	1.000	0.004	0.004	0.000
Fan test T2	20.365	0.282						
Fan test T3	20.290	0.283						
T test T1	13.305	0.330	42.000 (2)	0.000	1.000	0.004	0.004	0.000
T test T2	13.262	0.329						
T test T3	13.214	0.329						

Table 8. Continued

Test	Mean	SE	χ^2 (df)	Asymp.Sig.	Kendall's W	Adj. Sig. T1-T2	Adj. Sig. T2-T3	Adj. Sig. T1-T3
Illinois T1	19.977	0.258	42.000 (2)	0.000	1.000	0.004	0.004	0.000
Illinois T2	19.907	0.257						
Illinois T3	19.838	0.256						
5–10–5 Pro-Agility T1	6.290	0.089	41.518 (2)	0.000	0.989	0.006	0.003	0.000
5–10–5 Pro-Agility T2	6.268	0.088						
5–10–5 Pro-Agility T3	6.244	0.087						
Edgren T1	17.048	0.362	21.535 (2)	0.000	0.513	0.228	0.368	0.003
Edgren T2	17.429	0.328						
Edgren T3	17.762	0.337						
10 × 5 m Shuttle T1	20.850	0.281	36.286 (2)	0.000	0.864	0.004	0.016	0.000
10 × 5 m Shuttle T2	20.790	0.281						
10 × 5 m Shuttle T3	20.729	0.280						
Compass Drill T1	7.754	0.176	40.095 (2)	0.000	0.955	0.002	0.010	0.000
Compass Drill T2	7.717	0.179						
Compass Drill T3	7.702	0.174						
Box Drill T1	13.200	0.292	42.000 (2)	0.000	1.000	0.004	0.004	0.000
Box Drill T2	13.160	0.293						
Box Drill T3	13.109	0.293						

Note. Adj. Sig. Bonferroni correction (p = 0.0167).

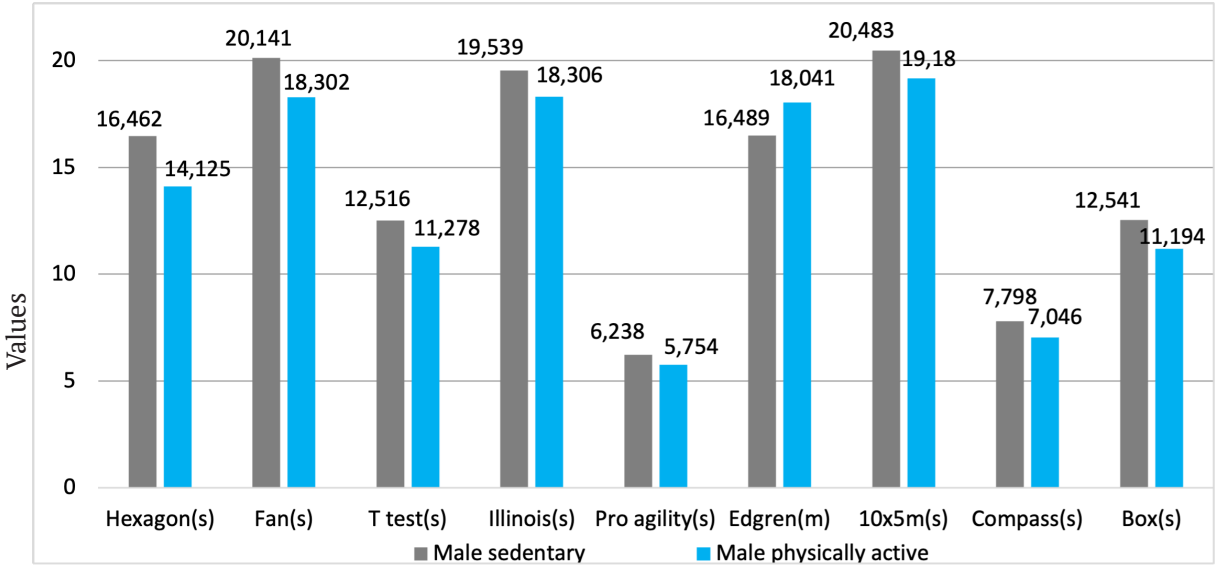

Figure 1. Estimated marginal means for males (sig. <0.05)

The χ^2 values (df = 2) indicate significance levels (p < 0.05) for all nine tests. Effect size expressed by Kendall›s coefficient of concordance (Kendall›s W) has very high values (> 0.71) for most tests. The exception is the Edgren test, where moderate to large effects are reported (Kendall›s W = 0.513). For this test, significant progress was identified only at the level of the entire study year (T1–T3). For the data pairs T1–T2 and T2–T3, insignificant improvements were noted at the semester level (Adj. Sig. > 0.0167). However, both genders register statistically significant progress (p < 0.05) throughout the entire academic year (T1–T3). This indicates clear improvements for the entire battery of tests.

Figure 1 and 2 compare the estimated mean values for males and females depending on the level of physical activity (sedentary vs. physically active). All differences recorded in the tests are statistically significant (p < 0.05). Sedentary subjects show lower scores than physically active ones (longer times obtained in the timed tests and a shorter distance in the Edgren test).

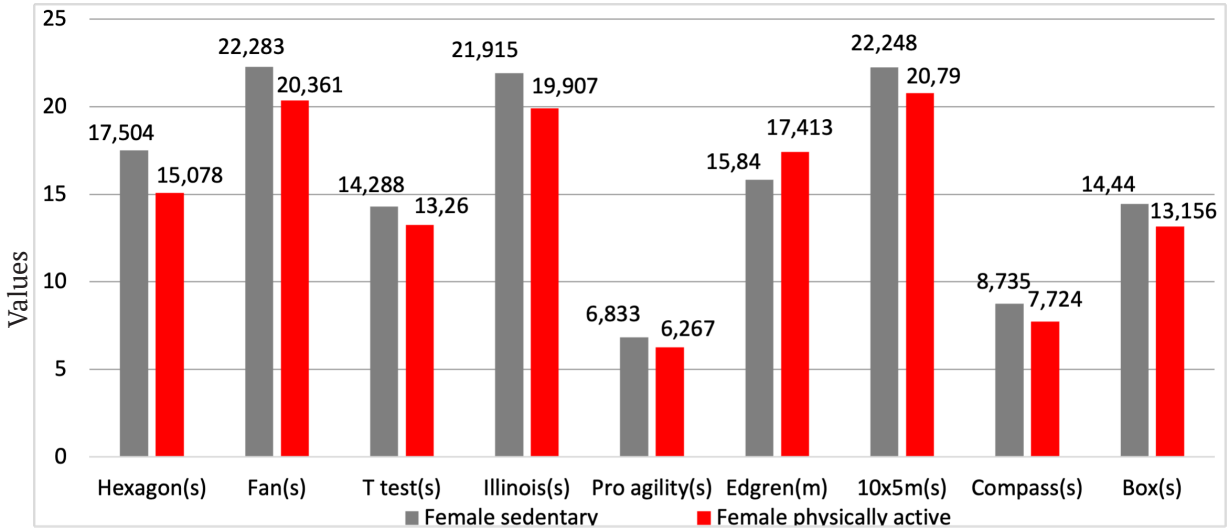

Figure 2. Estimated marginal means for females (sig. <0.05)

Discussion

The purpose of the present study was to develop, implement, and evaluate the effectiveness of an experimental programme aimed at improving non-reactive agility (change of direction speed) in university students with non-sports specialization. The programme was based on two categories of exercises (ladder and cones) integrated into regular physical education classes throughout the academic year. The evaluation was conducted through three testing moments and included nine non-reactive agility tests applied separately according to gender and level of physical activity. The results indicate significant improvements in agility performance for most tests and groups of students. Statistically significant differences were identified between the initial and final testing moments for both genders and for sedentary and physically active students. The effect size values also confirm strong practical effects of the implemented programme in most cases. Some isolated exceptions were identified, mainly in the case of male students, where insignificant improvements were observed during individual semesters. However, the comparison between the initial and final measurements confirms the overall effectiveness of the proposed training structures. These findings indicate that the systematic use of ladder and cone exercises within physical education lessons can contribute to the development of change-of-direction ability in university students.

The increasing orientation of students towards sedentary activities and the role of physical effort in improving academic performance and lifestyle are also analyzed in other studies [36]. Replacing classic soccer training methods with small-sided games is more effective in increasing performance in agility tests. The applied solution (20 weeks × 3 training sessions) for young players (16–18 years old) facilitates obvious progress in the 5-10-5 Pro-Agility test, from 5.50 s to 5.18 s for the experimental group. The control group shows lower progress, from 5.54 s to 5.41 s [37]. Adaptation to the surface, as well as the neuromuscular and coordination qualities of athletes, are more important in agility tests than the equipment or footwear used. The use of American football cleats versus soccer cleats for young people from the USA (21.1 years old) does not generate differences in the 5-10-5 Pro-Agility test. In both situations, similar values of 5.00 s are obtained [38]. The successive application of the 5-10-5 Pro-Agility test (three tests with a one-week interval; 5 yards = 4.57 m) on New Zealand student athletes (18.1 years) reported significant differences between sessions 2 and 3. The values are relatively close: 5.03 s (S1), 5.04 s (S2), and 5.01 s (S3) [39]. Improving agility indicators requires diversified methods and exercises. The comparison between ladder training (unidimensional movements) and cube training (multidimensional movements), applied for 8 weeks × 2 sessions to college students in Texas, USA, highlights the significant efficiency of both solutions. In the 5-10-5 Pro-Agility test, the ladder group achieves 5.56 s at baseline and 5.34 s at final testing, while the cube group achieves 5.37 s at baseline and 5.23 s at final testing [40]. All the performances analyzed in these studies for athletes in the 5-10-5 Pro-Agility test are better than the values obtained in our students.

A recent study proposes the use of exercises based on immersive virtual reality, which are more effective in optimizing the level of fitness than traditional variants. The application to university students (18–35 years, both sexes) in California, USA, for 4 weeks × 3 sessions × 45–60 minutes also demonstrates usefulness for sprint and non-reactive agility tests. In the 5-10-5 Pro-Agility test, the average results improve from 6.0 s to 5.7 s. In the group that used traditional exercises, no progress was reported [41]. These results are similar to those

obtained by active males in our study (5.74 s). Wearing work gear for police officers influences the results in fitness tests, but no significant differences were found between those who wore a duty belt for agility tests and those who did not. In the 5-10-5 Pro-Agility Shuttle, loaded females scored 8.9 s and unloaded females scored 10.8 s. For males, the situation is reversed: 9.8 s in the loaded version and a better value in the unloaded condition, 8.4 s [42]. The scores recorded by both sexes in our study indicate higher values. However, they should be viewed with caution due to the different testing conditions.

The use of SAQ training (Speed, Agility, Quickness) applied for Chinese university students practicing martial arts (Wushu) (8 weeks × 5 weekly sessions) ensures an improvement in non-reactive agility. The experimental group obtained 20.14 s at the initial testing and 16.83 s at the final testing in the Illinois Agility Test. The control group obtained 21.52 s at the initial testing and 20.45 s at the final testing [43]. Agility training and sprints over different distances are useful in the training of police officers. Positive associations were found between short-distance acceleration capacity and agility values. Students at the Faculty of Security Studies at the University of Banja Luka obtained a mean score of 16.54 s on the Illinois Agility Test (IAT), with extreme values of 15.48 s and 18.27 s [44]. Plyometric exercises applied for six weeks in the training programme of Indonesian badminton players (mostly males, 20–24 years old) ensure the improvement of non-reactive agility indicators. The experimental group obtained 18.31 s at the initial testing and 16.38 s at the final testing in the Illinois Agility Test [45]. All these studies indicate superior final results compared to the male groups tested in our study for the Illinois Agility Test.

Significant correlations between different fitness measurements and the values of the ability to change direction (CODS) are found for female police officers from Abu Dhabi (32.19 years old). For the classic version of the Illinois Agility Test, an average performance of 23.17 s is obtained. For the Illinois Agility Test loaded with 10 kg, an average value of 24.14 s is reported [46]. Implementing specific ladder agility exercises in the extracurricular training of Indonesian students (indoor soccer players) resulted in improved Illinois Agility Test results, with a final mean value of 18.99 s [47]. These studies report lower Illinois Agility Test scores than those obtained by our groups (18.30 s for active males and 19.54 s for active female students). The specific physical demands of university students in Serbia (police officer specialization) correspond to high-intensity efforts in anaerobic mode. For change of direction speed (CODS), evaluated by the Illinois Agility Test, average performances of 20.54 s for females (17.55 s and 22.96 s extreme values) and 18.06 s for males (15.82 s and 19.91 s extreme values) are reported [48]. Active males in the group studied by us have poorer results, while active females have a better score.

The efficiency of plyometric training is reflected in its effects on muscle power and agility values. The application of these exercises for 6 weeks on young subjects from the USA (24.2 years) ensures significant progress in the Illinois test (17.1 s vs. 16.6 s) and the T test (12.8 s vs. 12.1 s) [49]. Active males in our group have lower mean values for the Illinois test, but better values for the T test.

Non-reactive agility testing of physically active American military men (26.2 years old) on two consecutive days demonstrated good test–retest reliability. For the Edgren Side Step (ESST), values of 23.89 and 24.27 m are obtained. For the T test, the performances are 12.27 and 12.19 s. For the Illinois Agility Test (IAT), values of 18.26 and 18.18 s are obtained [50]. Lower values for the Edgren Side Step were identified for physically active males in the present study (18.04 m), slightly lower values for the Illinois test, but better values for the T test (11.28 s).

Agility tests are included in the Comprehensive High-Level Activity Mobility Predictor (CHAMP) for military males with and without traumatic lower-limb loss (LLL). The application of the tests indicates large differences between subjects with and without LLL: 25.5 s and 12.2 s for the T test, 32.1 s and 18.2 s for the Illinois test, and 15.4 m and 24.3 m for the Edgren Side Step test [51]. For the Illinois test, the active males investigated in our study obtain similar values. However, for the Edgren Side Step test, the results are clearly weaker.

Agility testing in different sports should be performed using tests based on the movement patterns and the specific skills required in the respective sport. In badminton, the X test is proposed, which shows strong and significant correlation coefficients with classic agility tests. The analyzed group (young male university students, 21.56 years old, from Iran) obtained 15.83 s in the Illinois test and 10.23 s in the T test [52]. The results of our students are much weaker in these two tests compared with those reported in this study.

The Speed, Agility, and Quickness training method (SAQ) is more effective in optimizing values in non-reactive agility tests for Chinese university students (19.58 years old) practicing Sanda (a style of martial arts) than traditional variants. The experimental group obtained a value of 7.26 s in the Pro-Agility test (5-10-5), and the control group 7.35 s. In the Illinois test the results were 22.29 s versus 22.46 s, and in the Compass Drill 7.91 s versus 8.16 s [53]. However, our group of active males achieves higher average results in all these tests, for example 7.04 s in the Compass Drill.

The use of agility tests (T test) differentiates the quality of athletes with high and low levels of

training. It is considered useful and recommended for volleyball, basketball, soccer, and American football. Investigations on university students with different levels of fitness (22.3 years for males and 22.4 years for females) from the USA obtained the following results for the T test: low sport (female 13.55 s, male 11.20 s), recreational sport (female 12.52 s, male 10.49 s), and college athletes (female 10.94 s, male 9.94 s). For the Hexagon test, the following scores were obtained: low sport (female 14.31 s, male 14.20 s), recreational sport (female 13.21 s, male 12.33 s), and college athletes (female 12.87 s, male 12.29 s). Strong negative and significant associations between agility tests and vertical jump were found [54]. Only active subjects of both genders tested in our study have values similar to the low sport category for the two tests. Compared with higher categories of involvement in sports activities, the results indicate a weaker level.

The use of specific exercises for the development of non-reactive agility in physical education lessons (frontal, lateral, and backward movements, and changes of direction at variable angles) for Romanian pubertal students (12-week training) indicates significant progress. The experimental group (subjects of both genders) obtained the following results at the initial and final tests: Illinois test (21.73 s and 20.60 s), T test (16.42 s and 15.36 s), Compass Drill (10.06 s and 9.23 s), and Box Drill (14.26 s and 12.19 s) [55]. However, these values cannot be compared with the data obtained in our study due to the mixed groups and classification in a different age stage.

Determining the fitness level of female university students (3rd year of undergraduate studies, over 22 years old) with the specialization of physical education and sports from Niš, Serbia indicates the following values for the 10 × 5 m agility test: an average value of 21.63 s, with extreme scores of 18.43 s and 24.05 s [28]. Our group of active females obtains better results (20.79 s), while sedentary females show weaker results (22.25 s). These findings support the general assumption that a higher level of regular physical activity contributes to better agility performance, since training programmes focused on speed, agility, and quickness have been shown to significantly improve change-of-direction abilities and overall agility performance [56].

Analysis of the fitness level based on the Eurofit tests for male university students from Saudi Arabia (18–22 years old) indicates an average value of 22.8 s for the 10 × 5 m Shuttle Run test. The extreme values recorded are 13.3 s (best performance) and 36.2 s (worst performance) [57]. By comparison, the male students tested in our study obtained better average performances, especially the physically active group (19.18 s).

Endurance and strength training (6 weeks × 3–4 sessions with different orientations: HIIT, full-body, and turbo) applied to non-athletic Polish female university students (24.09 years) leads to improvement of fitness level indicators. In the agility test 10 × 5 m shuttle run, an average result of 21.22 s is obtained at the initial testing and 20.43 s at the final testing [58]. The level of involvement in physical activities, fitness level values, and body composition differ for Polish university students depending on the university specialization. The best results in the 10 × 5 m shuttle run were obtained by the Physical Education specialization (18.81 s for females and 17.33 s for males). These were followed by Physiotherapy students (21.70 s for females and 18.91 s for males). The lowest results were recorded for students from the SSHE (State School of Higher Education) (21.82 s for females and 19.97 s for males) [59]. A study on the university population in Slovakia (20.73 years) measured the values of motor performance for students with various specializations. Students from Physical Education and Sports obtained the best results, with significant differences for both sexes. In the 10 × 5 m shuttle run test, physical education students achieved 16.97 s for males and 17.86 s for females. Medical students achieved 18.60 s for males and 21.04 s for females. Chemistry and nutrition students achieved 18.82 s for males and 21.83 s for females. Natural sciences students achieved 19.06 s for males and 20.21 s for females [60]. Our groups have similar performances to the non-sports majors listed in the 10 × 5 m shuttle run test, but they are weaker than those of students with sports majors.

Plyometric exercises (applied for 6 weeks × 2 sessions) for recreational soccer players from Malaysia (21.55 years) facilitate significant progress in sprint and agility tests. The initial mean value for the T test is 12.88 s, and the final value is 12.58 s, representing a progress of 2.32% [61]. Ladder training exercises are effective in increasing change-of-direction speed (CODS) performance for Indian university soccer students (21.20 years). The use of ladder drills training (6 weeks × 3 sessions × 30 minutes) improved the result in the T test from 12.24 s to 11.19 s [62]. In the T test, physically active males in the present study obtained values similar to those reported in the presented study.

Success in tennis and solving game situations are conditioned by the execution of fast movements in various directions, in quick response to the trajectory of the ball and the position of the opponents. In this sense, agility is highly demanded. Bulgarian university students practicing tennis obtained the following results in agility tests. For the Compass test, the results are: males (average 10.36 s, extreme values 9.18 s and 12.56 s) and females (average 11.25 s, extreme values 10.02 s and 13.45 s). For the Fan test, the obtained results are: males (average 16.97 s, extreme values 15.05 s and 20.22 s) and females (average 19.04 s, extreme values 16.61 s and 22.77

s) [63]. Speed, agility, and muscle strength training (defining factors for performance in tennis) must be correlated with the level of biological maturation of young Slovenian players. In this context, females can start this training earlier, but males achieve superior results. Very strong associations are found between agility tests and the short 5 m sprint in males. For females, moderate correlations between agility and the 20 m sprint are reported. For the Fan drill test (five directions, 4–4.5 m), U16 males achieve 14.1 s and U18 achieve 13.4 s. For U16 females, a value of 15.4 s and 15.0 s for U18 was recorded [64]. Our better results in the Compass test (7.04 s for active males and 7.72 s for active females) may be explained by a greater distance travelled from the center marker to the extremities in the analyzed study. For the Fan test, our groups record weaker performance values (18.30 s for active males and 20.36 s for active females). This difference can be explained by the fact that the comparison is made with performance athletes.

Repeated performance measurements on a university population (25.35 years, both genders) indicate a high level of reliability for the Hexagon agility test, especially for injury-free groups. Significant differences in performance are measured only between the test times on the same day (T1–T2), with a difference of one hour. This may be an effect of understanding and memorizing the route. No significant differences are reported for tests performed on different days (T2–T3): T1 = 13.83 s, T2 = 12.64 s, and T3 = 12.46 s [65]. Compared with these scores, the average performances of the groups tested in our study are weaker in the Hexagon test (15.97 s for active females and 14.2 s for active males).

Limitations of the study and future directions of investigation

The absence of a control or comparator group is the main limitation of the study. The large number of independent and dependent variables analyzed did not allow the inclusion of all relevant data associated with the study in this manuscript. The results were not correlated with explosive power tests or short-distance sprints, which strongly influence change-of-direction speed. In future publications, the influence of different factors affecting agility indices in students (e.g., age and anthropometric dimensions) will be presented [66]. BMI level will also be analyzed as a predictor of performance in non-reactive agility tests [67, 68, 69]. Another complementary research direction is reactive agility testing. This approach allows the study of subjects under conditions in which the completion of test routes is conditioned by the ability to respond to visual stimuli that appear unexpectedly. Such situations are frequently encountered in the real demands of sports games [70].

Conclusions

Statistical indicators confirm the usefulness of the experimental programme proposed for university students. The programme aims to improve non-reactive agility indicators for both genders and levels of physical activity. The use of diversified exercise structures based on ladders and cones increases the level of student involvement in the lesson and facilitates significant progress throughout the academic year for most of the applied tests. Even though the agility performances of physically active students are influenced by other external variables that are difficult to quantify (specific demands of sports or active leisure activities practiced), for sedentary student groups the positive influence of the implemented motor structures is supported by the effect size values (Cohen's d). The results obtained are similar to those reported in other investigations on university students, but they are lower compared with performance athletes of the same age range. The number of physically active female students participating in the study (less than 10% of the total) indicates a dominant orientation of young people towards sedentary activities. This aspect negatively influences the skill-related fitness components in which agility is included.

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Conflict of interest

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

References

1. Forster JWD, Uthoff AM, Rumpf MC, Cronin JB. Pro-agility unpacked: Variability, comparability and diagnostic value. *International Journal of Sports Science & Coaching*, 2022;17(5): 1225–1240. https://doi.org/10.1177/17479541211069338
2. Paul DJ, Gabbett TJ, Nassis GP. Agility in Team Sports: Testing, Training and Factors Affecting Performance. *Sports Medicine*, 2016;46(3): 421–442. https://doi.org/10.1007/s40279-015-0428-2
3. Matlák J, Tihanyi J, Rácz L. Relationship Between Reactive Agility and Change of Direction Speed in Amateur Soccer Players. *Journal of Strength and Conditioning Research*, 2016;30(6): 1547–1552. https://doi.org/10.1519/JSC.0000000000001262
4. Szabo DA, Neagu N, Sopa IS. Research regarding the development and evaluation of agility (balance, coordination and speed) in children aged 9-10 years. *Health, Sports & Rehabilitation Medicine*, 2020;21(1): 33–40. https://doi.org/10.26659/pm3.2020.21.1.33
5. Pavlinovic V, Foretic N, Versic S, Sekulic D,

Liposek S. Predictors of Reactive Agility in Early Puberty: A Multiple Regression Gender-Stratified Study. *Children*, 2022;9(11): 1780. https://doi.org/10.3390/children9111780
6. Domenico FD, Altavilla G, Raiola G. Relationship between Rapid Strength, Reactive and Strength and Agility in University Sports Students. *International Journal of Human Movement and Sports Sciences*, 2022;10(1): 98–103. https://doi.org/10.13189/saj.2022.100114
7. Joksimovic M. Differences between vertical jumps in elite female volleyball players. Reasons for lack of differences. *TRENDS in Sport Sciences*, 2024;31(2): 109–117. https://doi.org/10.23829/TSS.2024.31.2-6
8. Nejić K, Stanković M, Rančić D, Jelaska I, Pezelj L, Katanić B, et al. Associations Between Jump Performance, Speed, and COD Abilities in Young Elite Volleyball Players. *Applied Sciences*, 2025;15(17): 9489. https://doi.org/10.3390/app15179489
9. Stanković M, Katanić B, Govindasamy K, Badau A, Badau D, Masanovic B, et al. Seasonal Changes in Body Composition, Jump, Sprint, and Agility Performance Among Elite Female Handball Players. *Applied Sciences*, 2025;15(11): 5846. https://doi.org/10.3390/app15115846
10. Živoder I, Hodić V, Zaplatić Degač N, Potočnjak J, Arapović M, Kuzmić A, et al. Motor Capabilities and Body Composition in Health vs. Non-Health University Students: A Pilot Study. *Life*, 2025;15(10): 1504. https://doi.org/10.3390/life15101504
11. Pavlinović V, Foretić N, Kovačević N, Galić T, Lušić Kalcina L, Mihanović F, et al. Cognitive and Motor Capacities Are Poorly Correlated with Agility in Early Pubertal Children: Gender-Stratified Analysis. *Applied Sciences*, 2024;14(8): 3148. https://doi.org/10.3390/app14083148
12. Horníková H, Zemková E. Relationship between Physical Factors and Change of Direction Speed in Team Sports. *Applied Sciences*, 2021;11(2): 655. https://doi.org/10.3390/app11020655
13. Negra Y, Chaabene H, Hammami M, Amara S, Sammoud S, Mkaouer B, et al. Agility in Young Athletes: Is It a Different Ability From Speed and Power? *Journal of Strength and Conditioning Research*, 2017;31(3): 727–735. https://doi.org/10.1519/JSC.0000000000001543
14. Rauter S, Coh M, Vodicar J, Zvan M, Krizaj J, Simenko J, et al. Analysis of reactive agility and change-of-direction speed between soccer players and physical education students. *Human Movement*, 2018;19(2): 68–74. https://doi.org/10.5114/hm.2018.74061
15. Vrablanský M, Skala F, Vencúrik T. Enhancing change of direction speed in young soccer players through running technique training. *The Journal of Sports Medicine and Physical Fitness*, 2025;65(7). https://doi.org/10.23736/S0022-4707.25.16404-9
16. Okilanda A, Angelia L, Mayangsari R, Bais S, Desman MA, Cahyani FI, et al. Physical Performance Profiles of Junior Hapkido Athletes in West Sumatra: Comparative Insights with National-Level Standards. *Balneo and PRM Research Journal*, 2025;16(4):1–13. https://doi.org/10.12680/balneo.2025.913
17. Forster JWD, Uthoff AM, Rumpf MC, Cronin JB. Training to Improve Pro-Agility Performance: A Systematic Review. *Journal of Human Kinetics*, 2023;85(1): 35–51. https://doi.org/10.2478/hukin-2022-0108
18. Türkarslan B, Deliceoglu G. The effect of plyometric training program on agility, jumping, and speed performance in young soccer players. *Pedagogy of Physical Culture and Sports*, 2024;28(2): 116–123. https://doi.org/10.15561/26649837.2024.0205
19. Voisin MP, Scohier M. Effect of an 8-Week Plyometric Training Program with Raised Forefoot Platforms on Agility and Vertical Jump Performance. *International Journal of Exercise Science*, 2019;12(6): 491–504. https://doi.org/10.70252/FNWU6350
20. Marius S, Badau D, Dreve AA. Integrated Training Program for Rugby Sevens: A Multivariate Approach of Motor, Functional, and Metabolic Components. *Applied Sciences*, 2026;16(2): 664. https://doi.org/10.3390/app16020664
21. Boichuk R, Iermakov S, Podrigalo L, Bezyazychnyy B. Coordination abilities in young football players for improving training efficiency. *Human. Sport. Medicine*, 2018;18(5): 73–82. https://doi.org/10.14529/hsm18s10
22. Amani-Shalamzari S, Khoshghadam E, Donyaei A, Parnow A, Bayati M, Clemente FM. Generic vs. small-sided game training in futsal: Effects on aerobic capacity, anaerobic power and agility. *Physiology & Behavior*, 2019;204: 347–354. https://doi.org/10.1016/j.physbeh.2019.03.017
23. Akameze J, Tyoakaa A, Chukwudo D, Ugwueze F. Effect of 12-week Skill Training Programme on Selected Physical Fitness Indices Among Secondary School Female Football Players in Makurdi, Benue State, Nigeria. *American Journal of Sports Science*, 2025;13(3): 57–63. https://doi.org/10.11648/j.ajss.20251303.11
24. Dargham RMEA, Hussein OH, Saeed RMS. The effect of using exercises with the Blaze pod device on the development of two elements Agility and speed of reaction for female handball players. *The Scientific Journal of Sport Science & Arts,* 2023;075:68–86. https://doi.org/10.21608/ijssaa.2023.239314.2106
25. Ye J, Cheng R, Gao B, Wang Y, Wang Y. Scientific Assessment of Agility Performance in Competitive Sports: Evolution, Application, Reliability, and Validity. *Strength & Conditioning Journal*, 2025;47(1): 56–75. https://doi.org/10.1519/SSC.0000000000000862
26. Chaabene H, Prieske O, Negra Y, Granacher U. Change of Direction Speed: Toward a Strength Training Approach with Accentuated Eccentric Muscle Actions. *Sports Medicine*, 2018;48(8): 1773–1779. https://doi.org/10.1007/s40279-018-0907-3
27. Sopa IS, Pomohaci M. Study regarding the development of agility skills of students aged between 10 and 12 years old. *Timisoara Physical Education and Rehabilitation Journal*, 2016;9(17): 7–16. https://doi.org/10.1515/tperj-2016-0009
28. Ali SKS, Fadhil MAK, Ali AsKS. Effectiveness of Coordination and Agility Exercises on the

Performance of Basic Fencing Skills amongst University of Baghdad Students. *International Journal of Innovation*, 2019;7:117–28.
29. Labib Siena Ar Rasyid M, Wiriawan O, Siantoro G, Ardy Kusuma D, Rusdiawan A. Combination of plyometric and ladder drill: Its impact on improving speed, agility, and leg muscle power in badminton. *Jurnal SPORTIF : Jurnal Penelitian Pembelajaran*, 2023;9(2): 290–309. https://doi.org/10.29407/js_unpgri.v9i2.20468
30. Polsorn K, Singchainara J, Soachalerm A, Butcharoen S, Santiboon TT. The developments of goalball famous visually impaired blind athletes' agility using smart ladder drill prototype. *International journal of health sciences*, 2022; 184–202. https://doi.org/10.53730/ijhs.v6nS2.4994
31. Bana O, Mintarto E, Kusnanik NW. The Effect of Acceleration Sprint and Zig-zag Drill Combination to Increase Students' Speed and Agility. *Journal of Physics: Conference Series*, 2018;947: 012040. https://doi.org/10.1088/1742-6596/947/1/012040
32. Tong X, Liang YF, Tongdecharoen W. The effect of SAQ training on the agility of college students in higher education. *Library Progress International*, 2024;44(3):6064-6071.
33. Sandu A. Ethical and Legal Perspectives on Informed Consent in the Context of International Human Rights Law. *Logos Universality Mentality Education Novelty: Law*, 2025;13(1): 21–29. https://doi.org/10.18662/lumenlaw/13.1/95
34. Wood R. Topend Sports | Sports Science, Fitness Testing and Event Analysis [Internet]. Topend Sports. 2001 Jan [cited 2026 Jan 5]. Available from: https://www.topendsports.com/index.htm
35. Romanian Tennis Federation. Teste de evaluare fizică a jucătorilor convocaţi la lot [Physical evaluation tests for players selected to the national team] [Internet]. Bucharest: Romanian Tennis Federation; [cited 2026 Jan 5]. Available from: http://www.frt.ro/_public/resources/files/TesteFiziceLoturiNationale_final_V2.pdf (In Romanian).
36. Silisteanu SC, Silisteanu AE, Antonescu OR, Duica LC. Assessment of the physical and emotional health concerning the students' physical activity during the COVID-19 pandemic. Munteanu C (ed.) *Balneo and PRM Research Journal*, 2021;12(4): 426–432. https://doi.org/10.12680/balneo.2021.474
37. Sîrbu M, Hanţiu I. Management of effort intensity in young football players training with small-sided games. *Health, Sports Rehabilitation Medicine*, 2021;22(3): 166–170. https://doi.org/10.26659/pm3.2021.22.3.166
38. Mardis BR, Gassmann CG, Senchina DS. A Test of Soccer Cleats Compared to Football Cleats during Football Speed and Agility Drills: Do Soccer Cleats Make You Faster or More Agile? *Journal of Student Research*, 2017;6:97–102. https://doi.org/10.47611/jsr.v6i1.319
39. Forster JDW, Uthoff AM, Rumpf MC, Cronin JB. Advancing the pro-agility test to provide better change of direction speed diagnostics. *The Journal of Sport and Exercise Science*, 2021;5:101–6. https://doi.org/10.36905/jses.2021.02.02
40. Wagner MC, Oden GL, Glave P, Hyman WV. Development of Agility Utilising A Multidimensional Modality of Plyometrics. *Journal of Fitness Research,* 2014;3:49–59.
41. Mologne MS, Yamamoto T, Viggiano M, Blatney AE, Lechner RJ, Nguyen TH, et al. Field-based fitness measures improve via an immersive virtual reality exergaming platform: a randomized controlled trial. *Frontiers in Virtual Reality*, 2024;5: 1290711. https://doi.org/10.3389/frvir.2024.1290711
42. Haynes S-E. *In-Training Improvement: A Tactical Athletic Approach to Enhance the Performance and Wellness of Law Enforcement Officers*. [Master's thesis]. Liberty University; 2020.
43. Fang F, Xue B. An Experimental Study of SAQ Training on the Agility and Quality of Young Wushu Students. *Studies in Sports Science and Physical Education*, 2024;2(2): 15–23. https://doi.org/10.56397/SSSPE.2024.06.03
44. Streetman A, Paspalj D, Zlojutro N, Božić D, Dawes J, Kukić F. Association of shorter and longer distance sprint running to change of direction speed in police students. *Nauka, bezbednost, policija*, 2022;27(1): 5–13. https://doi.org/10.5937/nabepo27-36289
45. Irawan D. Six Weeks Progressive Plyometrics Training on Badminton Player's Agility. In: *Proceedings of the Health Science International Conference (HSIC 2017)*, Malang, Indonesia: Atlantis Press; 2017. https://doi.org/10.2991/hsic-17.2017.4
46. Orr RM, Kukić F, Čvorović A, Koropanovski N, Janković R, Dawes J, et al. Associations between Fitness Measures and Change of Direction Speeds with and without Occupational Loads in Female Police Officers. *International Journal of Environmental Research and Public Health*, 2019;16(11): 1947. https://doi.org/10.3390/ijerph16111947
47. Hidayat A. Effect of agility ladder exercises on agility of participants extracurricular futsal at Bina Darma University. *Journal of Physics: Conference Series*, 2019;1402(5): 055003. https://doi.org/10.1088/1742-6596/1402/5/055003
48. Janković R, Dopsaj M. Sprint running, agility and anaerobic endurance: Standards for the students at the University of Criminal Investigation and Police Studies. *Nauka bezbednost policija*, 2022;27(2): 45–58. https://doi.org/10.5937/nabepo27-36046
49. Miller MG, Herniman JJ, Ricard MD, Cheatham CC, Michael TJ. The effects of a 6-week plyometric training program on agility. *Journal of Sports Science & Medicine*, 2006;5(3): 459–465.
50. Raya MA, Gailey RS, Gaunaurd IA, Jayne DM, Campbell SM, Gagne E, et al. Comparison of three agility tests with male servicemembers: Edgren Side Step Test, T-Test, and Illinois Agility Test. *Journal of Rehabilitation Research and Development*, 2013;50(7): 951–960. https://doi.org/10.1682/JRRD.2012.05.0096
51. Gailey RS, Gaunaurd IA, Raya MA, Roach KE, Linberg AA, Campbell SM, et al. Development and reliability testing of the Comprehensive

High-Level Activity Mobility Predictor (CHAMP) in male servicemembers with traumatic lower-limb loss. *Journal of Rehabilitation Research and Development*, 2013;50(7): 905–918. https://doi.org/10.1682/JRRD.2012.05.0099
52. Nourian E, Samadikia S, Yousefi O. Developing Special Badminton Agility Test and Evaluating Its Convergence with Standardized Agility Tests in Trained Young Men. *Journal of Advanced Sport Technology*, 2021;5(1). https://doi.org/10.22098/jast.2021.1214
53. Si X, Liu Y, Feng X, Feng S. Experimental study on the impact of Speed-Agility-Quickness Training method on the agility performance of collegiate sanda specialty students. *PeerJ*, 2025;13: e19406. https://doi.org/10.7717/peerj.19406
54. Pauole K, Madole K, Garhammer J, Lacourse M, Rozenek R. Reliability and Validity of the T-Test as a Measure of Agility, Leg Power, and Leg Speed in College-Aged Men and Women: *Journal of Strength and Conditioning Research*, 2000;14(4): 443–450. https://doi.org/10.1519/00124278-200011000-00012
55. Milanović Z, Sporiš G, Trajković N, James N, Samija K. Effects of a 12 Week SAQ Training Programme on Agility with and without the Ball among Young Soccer Players. *Journal of Sports Science & Medicine*, 2013;12(1): 97–103.
56. Popović R. Evaluation of the Physical Fitness Level in Physical Education Female Students Using Eurofit-Test. *International Journal of Sports Science and Physical Education*, 2017;2(1): 1. https://doi.org/10.11648/j.ijsspe.20170201.11
57. Aboelwafa HS, Elkilany AM, Al-Hariri MT. Measurement of Physiological Fitness Level Among Male College Students in Dammam, Saudi Arabia Using the European Fitness Test–EuroFit. *Global Journal of Health Science*, 2019;11(11): 21. https://doi.org/10.5539/gjhs.v11n11p21
58. Görner K, Reineke A. The influence of endurance and strength training on body composition and physical fitness in female students. *Journal of Physical Education and Sport,* 2020;2020:2013–20. https://doi.org/10.7752/jpes.2020.s3272
59. Popławska H, Dmitruk A, Hołub W. Body Composition, Physical Fitness and Physical Activity Among Students from Universities in Biala Podlaska. *Polish Journal of Sport and Tourism*, 2020;27(1): 21–27. https://doi.org/10.2478/pjst-2020-0004
60. Lubica P, Gheorghe B, Jaromir S. Physical Development and General Motor Performance of Bratislava University Students. *Procedia - Social and Behavioral Sciences*, 2014;117: 741–747. https://doi.org/10.1016/j.sbspro.2014.02.292
61. Shamshuddin MHB, Hasan H, Azli MS, Mohamed MN, Razak FAA. Effects of Plyometric Training on Speed and Agility among Recreational Football Players. *International Journal of Human Movement and Sports Sciences*, 2020;8(5): 174–180. https://doi.org/10.13189/saj.2020.080503
62. Robin K, Raj LY. Impact of ladder training on the agility performance of footballers. *Int J Yogic Hum Mov Sports Sci,* 2019;4:779–81.
63. Kostadinov R. Study of the agility of movement of Sofia university students participating in tennis classes. *Trakia Journal of Sciences,* 2023;21:549–55.
64. Munivrana G, Filipčić A, Filipčić T. Relationship of Speed, Agility, Neuromuscular Power, and Selected Anthropometrical Variables and Performance Results of Male and Female Junior Tennis Players. *Collegium Antropologicum*, 2015;39 Suppl 1: 109–116.
65. Beekhuizen KS, Davis MD, Kolber MJ, Cheng MSS. Test-Retest Reliability and Minimal Detectable Change of the Hexagon Agility Test. *Journal of Strength and Conditioning Research*, 2009;23(7): 2167–2171. https://doi.org/10.1519/JSC.0b013e3181b439f0
66. Karadenizli Zİ, İlbak İ, Jorgić BM, Onu I, Coman MG, Iordan DA. The Relationship Between Anthropometric Characteristics, Chronological Age, and Training Age with Speed, Agility, and Explosive Power in Handball Players. *Applied Sciences*, 2025;15(11): 6276. https://doi.org/10.3390/app15116276
67. Lakhdari EV, Slusar A, Leuciuc FV. Body composition analysis and metabolic risk in women with reduced physical activity. *Balneo and PRM Research Journal*, 2025;No. 4, December 2025(Vol 16). https://doi.org/10.12680/balneo.2025.936
68. Osipov AY, Potop V, Nagovitsyn RS, Zemba EA, Knyazev AP, Orlova II, et al. Indicators of physical activity and fitness of male students at Russian universities. *Physical Education of Students*, 2020;24:40–6. https://doi.org/10.15561/20755279.2020.0105
69. Morais JFE, Larrière O, Bragada JAA, Bartolomeu RFB, Magalhães PM, Schnegg A, et al. Comparative analysis of physical fitness and body composition in first-year bachelor sports sciences students from France and Portugal. *BMC Sports Science, Medicine and Rehabilitation*, 2025;17(1): 315. https://doi.org/10.1186/s13102-025-01359-0
70. Badau D, Steff N, Badau A, Stoica M. Enhancing Lower-Limb Simple and Choice Reaction Time and Spatial Orientation in Junior Basketball Players by Implementing Fitlight Technology in Sports Training. *Perceptual and Motor Skills*, 2025;132(6): 1392–1417. https://doi.org/10.1177/00315125251347793

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ORIGINAL ARTICLE

Functional fitness characteristics of ultramarathon runners specialized in 50 km and 100 km distances

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Abstract

Background and Study Aim: Ultramarathon running represents a demanding form of endurance activity characterized by prolonged duration and substantial physiological load. Despite the application of various approaches to performance assessment, the relative contribution of different physiological characteristics to race performance across standard ultramarathon distances remains a subject of practical interest. The aim of this study was to identify and directly compare the functional fitness characteristics associated with race performance at 50 km and 100 km distances.

Material and Methods: Thirty-one experienced ultramarathon runners performed an incremental treadmill test to volitional exhaustion to determine maximal oxygen uptake (VO_2max), aerobic threshold (AeT), anaerobic threshold (AnT), and the corresponding running speeds and respiratory exchange ratio (RER). Body mass index (BMI) was also assessed. Correlation and linear regression analyses were used to examine the relationships between physiological variables and race performance.

Results: The relationships between physiological variables and race performance differed between the two distances. At 50 km, performance was primarily associated with aerobic power–related variables, including VO_2max (r = 0.79), running speed at VO_2max (r = 0.82), and body mass index (r = -0.82). At 100 km, stronger associations were observed for threshold-related variables, particularly running speeds at AeT (r = 0.78) and AnT (r = 0.76), while the association with BMI was weaker (r = -0.52). Average race speed corresponded to 71.7% of vVO_2max at 50 km and 62.5% at 100 km.

Conclusions: The findings indicate a distance-dependent shift in physiological characteristics associated with ultramarathon performance. Shorter ultramarathon distances are more closely associated with aerobic power–related variables, whereas longer distances show stronger associations with threshold-related characteristics. These results support the concept of distance-specific physiological profiles in ultramarathon running. From a practical perspective, training approaches may benefit from accounting for these differences, with relatively greater emphasis on higher-intensity variables at shorter distances and threshold-related characteristics at longer distances.

Keywords: ultramarathon, VO_2max, aerobic threshold, anaerobic threshold, running performance, 50 km, 100 km

Introduction

Ultramarathon running represents one of the most demanding forms of endurance activity, characterized by prolonged duration and high physiological strain. Performance in such events depends on the interaction of multiple factors, including aerobic capacity, metabolic efficiency, and fatigue resistance. The complexity of these interactions, combined with variability in race distances and conditions, makes ultramarathon performance a multifaceted phenomenon requiring detailed analysis.

An ultramarathon is defined as a running event involving distances longer than 42195 m [1] or lasting more than 6 hours [2]. Ultramarathon competitions are gaining increasing popularity both in Ukraine and worldwide. The number of ultramarathon finishers has increased more than 14-fold, from 37.5 thousand to 535 thousand between 1992 and 2022 [3]. The official disciplines in which the International Association of Ultrarunners registers world records include 50 km, 50 miles, 100 km, 100 miles, 6 hours, 12 hours, 24 hours, 48 hours, and 6 days [4]. Among these, the 50 km and 100 km distances are of particular importance, as world records in these disciplines are also ratified by World Athletics, and they represent some of the most commonly contested ultramarathon events. Over the past decade (2012–2022), the number of 100 km competitions worldwide has doubled (from 259 to 529), while the number of finishers reached 46,313 in 2022, representing a 24.2% increase compared to 2012 [5]. In parallel, performance levels have improved, as reflected by decreasing finishing times [6]. For example, the average speed of the top 100 finishers at the World 100 km Championships increased from 13.23 km/h in 2012 to 13.85 km/h in 2022 [5].

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Previous studies have demonstrated relationships between ultramarathon performance and variables such as maximal oxygen consumption (VO_2max), velocity at VO_2max, anaerobic threshold, and oxygen consumption at race pace [7, 8, 9, 10, 11]. However, these findings are largely derived from studies conducted at different distances and under varying conditions. For example, Sabater-Pastor et al. [12] examined a 166 km cross-country race, O'Loughlin et al. [11] analyzed a 62 km event, and Howe et al. [10] investigated an 80.5 km treadmill ultramarathon.

Ultramarathon disciplines encompass a wide range of distances and competition formats, which may require different physiological profiles for optimal performance. This is supported by the findings of Berger et al. [13], who demonstrated that oxygen consumption at competitive speed varies substantially depending on race duration and distance (e.g., 65–70% of VO_2max for 60 km versus approximately 40% for 24-hour events). These differences suggest that treating ultramarathons as a homogeneous category may obscure important distance-specific physiological characteristics.

Analysis of research findings has shown that ultramarathon performance is associated with a range of physiological variables, including aerobic capacity, threshold characteristics, and running economy. Researchers emphasize that the contribution of these factors may vary depending on race conditions, duration, and distance, reflecting the complex and multifactorial nature of ultramarathon performance. At the same time, the variability of studied distances and methodological approaches complicates the interpretation and direct comparison of existing results. This lack of consistency in the assessment of performance determinants continues to limit the identification of distance-specific physiological profiles in ultramarathon running.

Thus, despite the popularity of 50 km and 100 km races, existing studies typically examine ultramarathon performance determinants either across heterogeneous distances or within a single race format, without directly comparing standard ultramarathon distances under the same experimental conditions. As a result, it remains unclear whether the relative contribution of key physiological variables differs systematically between commonly practiced distances such as 50 km and 100 km.

It is hypothesized that performance determinants differ systematically between distances, such that 50 km performance is primarily influenced by aerobic power (VO_2max-related variables), whereas 100 km performance is more strongly associated with aerobic threshold characteristics and metabolic efficiency.

The aim of this study was to identify and directly compare the functional fitness characteristics associated with race performance at 50 km and 100 km distances.

Materials and Methods

Participants

A cross-sectional study involved 31 experienced ultramarathon runners who competed at distances of 50 km and 100 km. Participants were recruited through targeted invitations distributed via coaching networks and running communities. Eligibility was verified based on self-reported training history and confirmed participation in ultramarathon events (50 km and/or 100 km) within previous competitive seasons. Additional inclusion criteria included more than 3 years of regular endurance training and absence of acute injury at the time of testing.

The term "experienced" reflects a wide spectrum of performance levels, which was necessary for reliable correlation analysis. The data of 19 athletes (men, age 37 ± 4 years, body mass index 23 ± 2, VO_2max 57.0 ± 6.5 ml·min^{-1}) were used to analyze performance at the 50 km distance, whereas the data of 21 athletes (men, age 38 ± 6 years, body mass index 23 ± 2, maximum oxygen consumption 57.3 ± 6.0 ml·min^{-1}) were used for the 100 km distance.

The 50 km (n = 19) and 100 km (n = 21) groups partially overlapped, as some athletes participated in both distances. This reflects real competition participation patterns; therefore, datasets were analyzed separately for each distance to identify distance-specific performance determinants rather than to perform direct between-group comparisons.

The study procedures were approved by the Scientific Council of the National University of Ukraine on Physical Education and Sport (Registration No. 0121U108193) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to testing.

Research Design

Participants performed an incremental step test using an ergospirometric system (VIASYS LE 300 CE treadmill, Oxycon Pro JAEGER analyzer, Polar H10 chest pulse monitor, Lactate Plus lactate meter). Prior to each test, the gas analysis system was calibrated according to the manufacturer's guidelines using standard calibration gases, and the accuracy of treadmill speed was verified before each testing session. All tests were conducted under standardized laboratory conditions (temperature 20–22°C, relative humidity 40–60%). Standardized pre-test conditions included 48 hours of rest (no heavy exercise), 3 hours of fasting, and abstinence from stimulants (caffeine). The test protocol started at 8 km/h with increments of 1 km/h every 2 minutes until volitional exhaustion. Gas exchange variables were recorded continuously throughout the test.

The following variables were determined: maximal oxygen consumption (VO_2max), oxygen consumption at aerobic threshold (VO_2 at AeT), oxygen consumption at anaerobic threshold (VO_2 at AnT), running speed and respiratory exchange ratio (RER) at VO_2max, aerobic threshold, and anaerobic threshold. Data processing was performed using Labmanager v5.3.0 software. Body composition was assessed using a Tanita BC 545N analyzer, and body mass index was calculated. Metabolic thresholds were identified using standard ventilatory criteria. The aerobic threshold (AeT) was defined as the point at which the ventilatory equivalent for oxygen (VE/VO2) began to increase without a concurrent rise in VE/VCO2. The anaerobic threshold (AnT) was defined as the point of a secondary non-linear increase in ventilation (VE) accompanied by a consistent rise in VE/VCO2 (respiratory compensation point). Threshold determination was performed by experienced investigators. In cases of ambiguity, threshold values were verified through repeated inspection of ventilatory curves to ensure consistency.

Statistical analysis

All statistical analyses were performed using Microsoft Excel and Statistics Kingdom software. Data are presented as mean ± standard deviation. The normality of data distribution was assessed using the Shapiro–Wilk test. Depending on distribution characteristics, Pearson's or Spearman's correlation coefficients were used to evaluate relationships between functional fitness variables and race performance at 50 km and 100 km distances.

To assess the contribution of physiological predictors, linear regression analyses were conducted. Initially, univariate regression models were applied to examine the independent association of each variable with race performance. Subsequently, multivariate regression models were constructed to identify the most relevant predictors while accounting for interrelationships between variables. Predictor selection for multivariate models was based on statistical significance in univariate analysis and physiological relevance. Multicollinearity was assessed using correlation matrices, and highly correlated variables were not included simultaneously in the same model. Model assumptions, including linearity, normality of residuals, and homoscedasticity, were evaluated using residual diagnostics. The coefficient of determination (R^2) was used to estimate the explanatory power of each model. Statistical significance was set at $p < 0.05$.

Given the number of tested variables, the analysis was considered exploratory. Therefore, no formal correction for multiple comparisons was applied; however, the results were interpreted with caution, taking into account the increased risk of Type I error. Outliers were identified based on residual analysis and excluded only when clearly deviating from model assumptions. The number of excluded observations, if any, was minimal and did not affect the overall trends.

A partial overlap between the 50 km and 100 km datasets was present, as some participants contributed data to both distances. To address this, all analyses were conducted separately for each distance, and no direct statistical comparisons between groups were performed. Each dataset was treated as an independent observational subset in accordance with the exploratory design of the study.

Results

The main functional fitness indices of the athletes, obtained from the incremental test and body composition analysis, as well as race performance and competitive speed for the 50 km and 100 km distances, are presented in Table 1.

As shown in Table 1, athletes competing at 50 km demonstrated higher average running speed compared to those competing at 100 km, despite similar values of VO_2max and body mass index. At the 50 km distance, faster athletes (finishing time < 4 h) maintained running speeds exceeding their aerobic threshold, whereas slower athletes performed below this level. In contrast, at the 100 km distance, competitive speed remained below the aerobic threshold regardless of performance level. On average, the difference between aerobic threshold speed and race speed at 100 km was 12.7% (1.6 $km \cdot h^{-1}$). Competitive speed corresponded to 62.5% of vVO_2max for the 100 km distance and 71.7% for the 50 km distance.

Correlation analysis revealed differences in the relationships between functional fitness characteristics and race performance at the 50 km and 100 km distances (Table 2).

As shown in Table 2, the pattern of relationships between physiological variables and race performance differed between the 50 km and 100 km distances. At the 50 km distance, performance was primarily associated with aerobic power and threshold-related variables, including VO_2max ($r = 0.79$), vVO_2max ($r = 0.82$), and velocities at anaerobic and aerobic thresholds ($r \approx 0.69–0.75$). Body mass index showed a strong negative association with performance ($r = -0.82$), while no meaningful relationships were observed for respiratory exchange ratio variables. At the 100 km distance, the pattern shifted toward a greater role of threshold-related variables, particularly velocities at aerobic and anaerobic thresholds ($r \approx 0.76–0.78$). Running velocity at VO_2max remained significantly associated with performance ($r = 0.72$), whereas VO_2max itself was not. In addition, respiratory exchange ratio at VO_2max showed a moderate positive relationship ($r = 0.57$). Body mass index

Table 1. Functional fitness indices of experienced ultramarathon runners

Variable	50 km (n = 19, age 37 ± 4 years)	100 km (n = 21, age 38 ± 6 years)
Race performance (h:min:s)	3:59:15 ± 00:46:33	09:23:12 ± 01:19:29
Average speed ($km \cdot h^{-1}$)	12.9 ± 2.0	10.9 ± 1.5
Body mass index	23 ± 2	23 ± 2
VO_2max ($ml \cdot min^{-1}$)	57.0 ± 6.5	57.3 ± 6.0
vVO_2max ($km \cdot h^{-1}$)	17.6 ± 1.6	17.7 ± 1.4
RER at VO_2max	1.08 ± 0.05	1.06 ± 0.09
VO_2 at AnT ($ml \cdot min^{-1}$)	50.0 ± 5.9	50.0 ± 6.0
vAnT ($km \cdot h^{-1}$)	14.9 ± 1.5	14.8 ± 1.5
RER at AnT	0.98 ± 0.05	0.94 ± 0.08
VO_2 at AeT ($ml \cdot min^{-1}$)	43.1 ± 5.0	41.7 ± 4.8
vAeT ($km \cdot h^{-1}$)	12.8 ± 1.4	12.6 ± 1.8
RER at AeT	0.91 ± 0.06	0.88 ± 0.08

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. Values are presented as mean ± standard deviation.

Table 2. Correlation between functional fitness characteristics and race performance at 50 km and 100 km distances

Variable	50 km (n = 19) r (p-value)	Interpretation	100 km (n = 21) r (p-value)	Interpretation
Age	0.079 (p = 0.749)	No significant relationship	-0.403 (p = 0.070)	No significant relationship
Body mass index	0.817 (p < 0.001)	Significant	-0.516 (p = 0.017)	Moderate
VO_2max	0.793 (p < 0.001)	Significant	0.414 (p = 0.070)	No significant relationship
vVO_2max	0.819 (p < 0.001)	Significant	0.720 (p < 0.001)	Significant
RER at VO_2max	0.065 (p = 0.792)	No significant relationship	0.567 (p = 0.014)	Significant
VO_2 at AnT	0.732 (p < 0.001)	Significant	0.432 (p = 0.057)	No significant relationship
RER at AnT	0.111 (p = 0.650)	No significant relationship	0.370 (p = 0.131)	No significant relationship
vAnT	0.749 (p < 0.001)	Significant	0.757 (p < 0.001)	Significant
VO_2 at AeT	0.672 (p = 0.002)	Significant	0.717 (p < 0.001)	Significant
RER at AeT	0.000 (p = 0.999)	No significant relationship	0.310 (p = 0.210)	No significant relationship
vAeT	0.690 (p = 0.001)	Significant	0.781 (p < 0.001)	Significant

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. r – correlation coefficient. Interpretation is based on statistical significance ($p < 0.05$).

demonstrated a moderate negative association (r = -0.52). The results indicate a distance-dependent shift from aerobic power–related variables at 50 km toward greater importance of threshold and efficiency-related characteristics at 100 km.

The results of the regression analysis, including coefficients of determination (R^2), demonstrated differences in the strength of associations between functional fitness characteristics and race performance depending on the competitive distance (Table 3).

As shown in Table 3, the strength of associations between functional fitness variables and race performance differed between the 50 km and 100 km distances. At the 50 km distance, performance was primarily associated with aerobic power–related variables, particularly running velocity at VO_2max and body mass index (both $R^2 \approx 0.67$). Threshold-related variables also showed consistent but slightly weaker associations. At the 100 km distance, the pattern shifted toward a greater role of threshold-related characteristics, with the strongest associations observed for running velocities at aerobic and anaerobic thresholds ($R^2 \approx 0.57–0.61$). Additional variables demonstrated moderate associations, while aerobic power (VO_2max) was not associated with performance.

The results indicate a distance-dependent shift from aerobic power–related characteristics at 50 km toward greater importance of threshold-

Table 3. Association between functional fitness characteristics and race performance at 50 km and 100 km distances (regression analysis)

Variable	50 km R^2	p-value	100 km R^2	p-value
Body mass index	0.67	< 0.001	0.27	0.017
VO_2max	0.63	< 0.001	–	–
vVO_2max	0.67	< 0.001	0.52	< 0.001
RER at VO_2max	–	–	0.32	0.014
VO_2 at AnT	0.54	< 0.001	–	–
vAnT	0.56	< 0.001	0.57	< 0.001
VO_2 at AeT	0.45	0.002	0.44	0.001
vAeT	0.48	0.001	0.61	< 0.001

Note: VO_2max – maximal oxygen consumption; vVO_2max – running speed at VO_2max; AnT – anaerobic threshold; AeT – aerobic threshold; RER – respiratory exchange ratio. R^2 – coefficient of determination. Values represent results of univariate linear regression models. "–" indicates no statistically significant association.

related variables at 100 km. These findings highlight the importance of considering distance-specific physiological profiles when analyzing ultramarathon performance.

Discussion

The present study provides a direct comparison of physiological performance-related variables between two standard ultramarathon distances within a single cohort using a unified testing protocol. In contrast to previous studies that examined isolated distances or heterogeneous race formats [9, 10, 14, 15], the findings indicate that the relative contribution of aerobic power and threshold-related variables differs depending on race distance.

The results show that functional fitness characteristics associated with race performance differ between the 50 km and 100 km distances. In particular, VO_2max was associated with performance at the 50 km distance but not at 100 km, whereas running velocity at VO_2max was associated with performance at both distances. These findings are consistent with previous research. A systematic review by Garbisu-Hualde [14] reported associations between VO_2max, vVO_2max, and ultramarathon performance across distances ranging from 42.2 km to 101 km; however, distance-specific differences in the contribution of these variables were not addressed. Fornasiero et al. [9] demonstrated a relationship between VO_2max and performance in a 65 km mountain race, while Balducci et al. [15] reported a significant association between vVO_2max and performance in a 75 km mountain ultramarathon. In contrast, Howe et al. [10], in a study of 80.5 km treadmill running, reported that VO_2max was not associated with performance, and highlighted running economy as a relevant factor.

In contrast to these studies [9, 10, 14, 15], the present results indicate that the role of VO_2max decreases with increasing race distance, while velocity-based variables remain consistently associated with performance. This suggests that treating ultramarathons as a homogeneous category may obscure distance-specific physiological differences. The observed associations between body mass index and race performance at both 50 km and 100 km distances are consistent with previous findings. Anthropometric characteristics, including body mass index, have been reported as relevant factors influencing endurance performance. In ultramarathon running, lower body mass and favorable body composition are associated with improved performance, likely due to reduced energy cost of locomotion and enhanced metabolic efficiency during prolonged exercise [16].

Hoffman et al. [17, 18] reported associations between body composition characteristics, including body mass index and fat mass, and ultramarathon performance. Similarly, Rüst et al. [19] demonstrated that body mass index and body fat were associated with performance in 100 km running. O'Loughlin et al. [11] found that body mass index was associated with finishing time in men, but not in women, during a 62 km ultramarathon. According to Denadai et al. [8], running speed during ultramarathon competitions typically corresponds to 50–70% of that at VO_2max, while oxygen consumption during competition ranges from 45% to 60% of VO_2max. These findings are consistent with the present results, where competitive speed corresponded to approximately 62.5% of vVO_2max at 100 km and 71.7% at 50 km.

The respiratory exchange ratio (RER) was also examined in relation to ultramarathon performance. This parameter reflects the ratio of carbon dioxide production to oxygen consumption and is commonly used as an indirect indicator of substrate utilization, with higher values associated with greater carbohydrate use and lower values with increased fat oxidation [20, 21].

Previous studies have suggested that RER may

be related to metabolic characteristics relevant to endurance performance. For example, Tanji and Nabekura [22] reported smaller changes in RER with increasing speed in faster runners compared to slower ones. In addition, RER has been discussed in relation to aerobic and anaerobic metabolic responses in trained athletes [23].

In the present study, no association was observed between RER and performance at the 50 km distance, whereas a significant relationship was identified between RER at VO_2max and performance at 100 km. Higher RER values at VO_2max were associated with higher running speed at this distance. This observation appears inconsistent with the commonly emphasized role of fat oxidation in ultra-endurance performance. However, the interpretation of RER in this context remains complex, as it reflects multiple physiological processes, including substrate utilization and buffering capacity. Therefore, the role of RER in relation to performance at different ultramarathon distances requires further clarification.

The present results also indicate that oxygen consumption and running velocity at aerobic and anaerobic thresholds are associated with race performance at both 50 km and 100 km distances. These variables have received limited attention in previous ultramarathon studies, particularly in the context of direct comparison between standard distances. The observed relationships suggest that threshold-related characteristics may contribute to performance differentiation across ultramarathon distances and should be considered alongside aerobic power variables when analyzing performance profiles.

Limitations and Future Research

The findings of this study should be interpreted in light of several limitations. A partial overlap of participants between the 50 km and 100 km groups may introduce non-independence of observations. Although analyses were conducted separately for each distance, this factor should be considered when interpreting the results. In addition, the observational and exploratory design, the interrelated nature of physiological variables, and the absence of full multivariate control for potential confounders limit the strength of inferences. The lack of correction for multiple comparisons also increases the risk of Type I error. Future research may further examine sex-specific differences in performance determinants, the role of threshold-related variables across different ultramarathon formats, and the contribution of metabolic indicators such as RER to performance outcomes.

Practical Implications

The results suggest that training approaches in ultramarathon running may benefit from considering distance-specific physiological profiles. For shorter ultramarathon distances (e.g., 50 km), aerobic power–related variables, including running velocity at VO_2max, appear to be more strongly associated with performance. In contrast, for longer distances (e.g., 100 km), threshold-related variables, particularly running velocities at aerobic and anaerobic thresholds, show stronger associations. These findings may be taken into account when structuring training programs, with consideration given to the relative emphasis on high-intensity and submaximal training components depending on race distance.

Conclusions

The present study demonstrates that physiological characteristics associated with ultramarathon performance differ between standard distances, indicating that 50 km and 100 km events should not be considered as a single homogeneous category. The findings suggest a distance-dependent shift in the relative role of physiological variables, with greater relevance of aerobic power–related characteristics at shorter ultramarathon distances and increased importance of threshold-related variables at longer distances. These observations support the concept of distance-specific physiological profiles in ultramarathon running and highlight the need to consider these differences when analyzing performance. From an applied perspective, the results suggest that training approaches and monitoring strategies may benefit from accounting for distance-specific demands, with emphasis on aerobic power and higher-intensity variables for shorter distances and threshold-related characteristics for longer distances.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

1. Popov S. Designing the training process of qualified ultramarathon runners on 100 km distance: retrospective analysis and modern approaches. *Theory and Methods of Physical Education and Sports*, 2022;(3):51-8. (In Ukrainian). https://doi.org/10.32652/tmfvs.2022.3.51-58
2. Scheer V, Basset P, Giovanelli N, Vernillo G, Millet GP, Costa RJS. Defining Off-road Running: A Position Statement from the Ultra Sports Science Foundation. *International Journal of Sports Medicine*, 2020;41(05): 275–284. https://doi.org/10.1055/a-1096-0980
3. DUV. *Ultra Marathon Statistics* [Internet]. DUV Ultra Marathon Statistics; [updated 2026 Jan; cited 2026 Jan 22]. Available from: https://statistik.d-u-v.org/

summary.php?&country=all&Submit_x=22&Submit_y=10&Language=RU&Language=EN
4. IAU. *International Association of Ultrarunners* [Internet]. IAU Records - IAU - International Association of Ultrarunners; [updated 2026 Jan; cited 2026 Jan 22]. Available from: https://iau-ultramarathon.org/iau-records.html
5. DUV. *Ultra Marathon Statistics* [Internet]. DUV Ultra Marathon Statistics; [updated 2026 Jan; cited 2026 Jan 22]. Available from: https://statistik.d-u-v.org/overview_champions.php#IAU100
6. Knechtle B, Knechtle P, Rosemann T, Senn O. What is associated with race performance in male 100-km ultra-marathoners – anthropometry, training or marathon best time? *Journal of Sports Sciences*, 2011;29(6): 571–577. https://doi.org/10.1080/02640414.2010.541272
7. Sovenko S, Popov S. Characteristics of functional preparedness as a basis for improving the training process of elite 100 km ultra-runners. *Theory and Methods of Physical Education and Sports*, 2023;(3):22-30. (In Ukrainian). https://doi.org/10.32652/tmfvs.2023.3.22-30
8. Denadai BS, Greco CC. Could middle- and long-distance running performance of well-trained athletes be best predicted by the same aerobic parameters? *Current Research in Physiology*, 2022;5: 265–269. https://doi.org/10.1016/j.crphys.2022.06.006
9. Fornasiero A, Savoldelli A, Fruet D, Boccia G, Pellegrini B, Schena F. Physiological intensity profile, exercise load and performance predictors of a 65-km mountain ultra-marathon. *Journal of Sports Sciences*, 2018;36(11): 1287–1295. https://doi.org/10.1080/02640414.2017.1374707
10. Howe CCF, Swann N, Spendiff O, Kosciuk A, Pummell EKL, Moir HJ. Performance determinants, running energetics and spatiotemporal gait parameters during a treadmill ultramarathon. *European Journal of Applied Physiology*, 2021;121(6): 1759–1771. https://doi.org/10.1007/s00421-021-04643-2
11. O'Loughlin E, Nikolaidis PT, Rosemann T, Knechtle B. Different Predictor Variables for Women and Men in Ultra-Marathon Running—The Wellington Urban Ultramarathon 2018. *International Journal of Environmental Research and Public Health*, 2019;16(10): 1844. https://doi.org/10.3390/ijerph16101844
12. Sabater-Pastor F, Tomazin K, Millet GP, Verney J, Féasson L, Millet GY. VO2max and Velocity at VO2max Play a Role in Ultradistance Trail-Running Performance. *International Journal of Sports Physiology and Performance*, 2023;18(3): 300–305. https://doi.org/10.1123/ijspp.2022-0275
13. Berger NJA, Best R, Best AW, Lane AM, Millet GY, Barwood M, et al. Limits of Ultra: Towards an Interdisciplinary Understanding of Ultra-Endurance Running Performance. *Sports Medicine*, 2024;54(1): 73–93. https://doi.org/10.1007/s40279-023-01936-8
14. Garbisu-Hualde A, Santos-Concejero J. What are the Limiting Factors During an Ultra-Marathon? A Systematic Review of the Scientific Literature. *Journal of Human Kinetics*, 2020;72(1): 129–139. https://doi.org/10.2478/hukin-2019-0102
15. Balducci P, Clémençon M, Trama R, Blache Y, Hautier C. Performance Factors in a Mountain Ultramarathon. *International Journal of Sports Medicine*, 2017;38(11): 819–826. https://doi.org/10.1055/s-0043-112342
16. Knechtle B, Nikolaidis PT. Physiology and Pathophysiology in Ultra-Marathon Running. *Frontiers in Physiology*, 2018;9: 634. https://doi.org/10.3389/fphys.2018.00634
17. Hoffman M. Anthropometric Characteristics of Ultramarathoners. *International Journal of Sports Medicine*, 2008;29(10): 808–811. https://doi.org/10.1055/s-2008-1038434
18. Hoffman MD, Lebus DK, Ganong AC, Casazza GA, Loan MVan. Body Composition of 161-km Ultramarathoners. *International Journal of Sports Medicine*, 2010;31(02): 106–109. https://doi.org/10.1055/s-0029-1241863
19. Rüst CA, Knechtle B, Knechtle P, Wirth A, Rosemann T. Body Mass Change and Ultraendurance Performance: A Decrease in Body Mass Is Associated With an Increased Running Speed in Male 100-km Ultramarathoners. *Journal of Strength and Conditioning Research*, 2012;26(6): 1505–1516. https://doi.org/10.1519/JSC.0b013e318231a7b5
20. Ramos-Jiménez A, Hernández-Torres RP, Torres-Durán PV, Romero-Gonzalez J, Mascher D, Posadas-Romero C, et al. The Respiratory Exchange Ratio is Associated with Fitness Indicators Both in Trained and Untrained Men: A Possible Application for People with Reduced Exercise Tolerance. *Clinical medicine. Circulatory, respiratory and pulmonary medicine*, 2008;2: CCRPM.S449. https://doi.org/10.4137/CCRPM.S449
21. Simonson DC, DeFronzo RA. Indirect calorimetry: methodological and interpretative problems. *American Journal of Physiology-Endocrinology and Metabolism*, 1990;258(3): E399–E412. https://doi.org/10.1152/ajpendo.1990.258.3.E399
22. Tanji F, Nabekura Y. Oxygen uptake and respiratory exchange ratio relative to the lactate threshold running in well-trained distance runners. *The Journal of Sports Medicine and Physical Fitness*, 2019;59(6). https://doi.org/10.23736/S0022-4707.18.08828-X
23. Frandsen J, Beck T, Langkilde CH, Larsen S, Dela F, Helge JW. The training induced increase in whole-body peak fat oxidation rate may be attenuated with aging. *European Journal of Sport Science*, 2021;21(1): 69–76. https://doi.org/10.1080/17461391.2020.1721563

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