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Acute effects of plyometric-dynamic stretching sequencing on athletic and neuromuscular performance in soccer players: a randomized crossover trial

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Abstract

Background Dynamic stretching (DS) and plyometric exercises are commonly incorporated into warm-ups to acutely enhance athletic performance through increased range of motion, reduced muscle stiffness, and post-activation performance enhancement. However, the optimal sequencing of these two modalities prior to sport-specific activities remains unclear. This randomized crossover trial compared the acute effects of DS followed by vertical drop jumps (DJ) versus the reverse sequence on key athletic and neuromuscular performance outcomes in male amateur soccer players.

Methods Twenty male amateur soccer players (age 20.5 ± 1.7 years; height 176.6 ± 4.3 cm; body mass 71.9 ± 4.6 kg) completed three conditions in counterbalanced order: DS + DJ, DJ + DS, and a control condition (CC) consisting of standard dynamic activities only. Each session was separated by a minimum of 72 h. Outcomes included L-drill maneuverability, modified repeated sprint ability (RSA) total time and fatigue index, 10 m linear sprint speed, countermovement jump (CMJ) height, and standing broad jump distance.

Results Significant Condition × Time interactions favored the DS + DJ sequence for L-drill agility ($\eta^2 = 0.43$, $p < 0.001$), 10 m sprint ($\eta^2 = 0.35$, $p = 0.002$), CMJ height ($\eta^2 = 0.28$, $p = 0.002$), and standing broad jump ($\eta^2 = 0.18$, $p = 0.03$). DS + DJ produced significant improvements from pre- to post-warm-up in L-drill ($\Delta = -0.15$ s, d = 0.78), 10 m sprint ($\Delta = -0.05$ s, d = 0.65), CMJ height ($\Delta = +1.23$ cm, d = 0.29), and broad jump distance ($\Delta = +4.20$ cm, d = 0.38). By contrast, neither DS + DJ nor DJ + DS enhanced RSA total time or fatigue index (both $p > 0.05$).

Conclusions Performing DS before plyometric conditioning improves single-effort sprinting, jumping, and pre-planned change of direction but not repeated sprint ability. Coaches should use DS + DJ sequencing to acutely enhance neuromuscular performance in soccer players.

Trial registration Iranian Registry of Clinical Trials (IRCT), IRCT20230612058457N9. Registered 23 May 2026 (retrospectively registered), https://irct.ir/trial/90268.

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Keywords Warm-up sequencing, Post-activation performance enhancement, Priming, Pre-performance conditioning

Background

Soccer is an intermittent high-intensity sport characterized by repeated bouts of sprinting, jumping, and changes of direction interspersed with periods of lower-intensity activity [1]. High-intensity actions typically occur every 30–120 s [1, 2]. The ability to repeatedly produce maximal power, impulse, sprinting actions (i.e., repeated sprint ability (RSA)), is consistently associated with higher soccer playing level and match performance [3]. Notably, peak periods of high-speed running and sprinting occur most frequently in the beginning of each half (21–28% of peak periods) compared to the final 15 min of each half (5–11%) [4], and match goals are more frequently scored in the opening minutes of each half [5]. These periods directly follow the warm-up, meaning acute performance gains from pre-performance conditioning may carry immediate competitive value. Consequently, designing effective warm-up (i.e., pre-performance conditioning) strategies that acutely enhance impulsive performance and high intensity actions is a central priority for sports scientists and practitioners [6]. Contemporary warm-up and pre-conditioning research has increasingly incorporated lower-limb dynamic and plyometric exercises, which demonstrate favorable acute performance effects compared to traditional static stretching [7–9]. DS enhances range of motion and reduces muscle stiffness [7], while plyometric exercises may elicit post-activation performance enhancement (PAPE) through mechanisms such as increased neural drive, muscle temperature, and muscular and cellular water content [10, 11]. However, despite the individual benefits of each modality, the optimal sequencing of DS and plyometrics within a warm-up or pre-conditioning strategy remains unclear [6]. Emerging evidence from track athletes suggests that exercise order meaningfully influences linear sprint performance [6]. For example, Silva et al. [6] demonstrated that performing two leg swing exercises (15 repetitions each) before three vertical drop jumps (DJ) improved late acceleration (30–50 m), whereas the reverse order (DJ before dynamic stretching (DS)) impaired initial acceleration (0–10 m) [6]. The authors proposed that DS prior to plyometrics may enhance muscle compliance, while plyometrics first may induce transient fatigue that masks potentiating effects [6]. Whether these sequencing effects apply to other high-intensity actions such as multi-directional speed, vertical and horizontal jumping, and RSA remains unknown [6].

Soccer involves biomechanical demands distinct from track athletics, including frequent changes of direction, acceleration from varied starting positions, and cutting maneuvers at multiple angles [12, 13]. Moreover, soccer players repeatedly perform high-intensity actions with incomplete recovery, a context that may differentially tax the balance between potentiating and fatiguing effects of various warm-up sequences [14]. Current warm-up guidelines for soccer remain largely inferential, extrapolated from linear sprint studies or isolated warm-up components rather than interactive sequencing effects [8, 15, 16]. Previous research has suggested that athletes with greater lower-body strength or power may exhibit larger PAPE responses, making baseline lower-body power a plausible moderator of the acute effects of warm-up sequencing [11]. As such, this study had three aims: (1) to compare the acute effects of DS followed by drop jumps (DS + DJ) versus drop jumps followed by DS (DJ + DS) on athletic and neuromuscular performance outcomes; (2) to exploratorily examine whether baseline lower-body power was associated with the magnitude of the performance response to the conditioning interventions; and (3) to explore, as a hypothesis-generating subgroup analysis, whether responses differed according to playing position. The primary hypothesis was that performing DS + DJ would result in greater acute enhancements in athletic and neuromuscular performance than DJ + DS or the control condition (CC). A secondary, exploratory hypothesis was that baseline lower-body power would be associated with the magnitude of the performance response to the conditioning interventions.

Methods

Trial design and participants

This study employed a randomized, crossover design with repeated measures. Each participant completed three experimental conditions in a counterbalanced order: (1) DS + DJ, (2) DJ + DS, and (3) CC consisting of a standard warm-up only. A crossover design was selected to allow each participant to serve as their own control, thereby reducing between-subjects variability and increasing statistical power for detecting within-subject differences between warm-up sequences. Each participant attended five total sessions over a three-week period, all scheduled between 2:00 and 4:00 p.m.: two familiarization sessions during week 1, followed by three experimental sessions during weeks 2 and 3. Experimental sessions were separated by a minimum of 72 h to ensure complete recovery and to avoid carryover effects. Participants were instructed to avoid lower-body resistance training for 48 h prior to each experimental session and to refrain from consuming caffeine for 3 h prior to testing. Participants were asked to maintain their habitual diet and hydration patterns across all testing sessions and to wear the same footwear for each session. The trial protocol

was registered retrospectively in the Iranian Registry of Clinical Trials (IRCT; IRCT20230612058457N9) on May 23, 2026. The reporting of this trial follows the CONSORT 2025 statement for randomized trials [17]. Participants were recruited from competitive amateur soccer clubs in Sivas, Türkiye, between March 16 and March 29, 2026. Familiarization took place from March 30 to April 5, 2026, and testing occurred from April 6 to May 3, 2026. According to the participant classification framework by McKay et al. [18], this study is classified as Tier 2 (trained/developmental), representing soccer players with regular structured training (3–4 sessions per week). Eligible participants were those who: (a) were male soccer players aged 18 to 25 years; (b) competed at the university or competitive amateur club level; (c) completed a minimum of three training sessions and one match per week; (d) played in one of the following field positions: forward, midfielder, or full-back; (e) had at least six months of structured soccer training; and (f) reported no lower limb injuries in the preceding three months. Exclusion criteria were: (a) being a goalkeeper; (b) being a central defender (due to distinct physical demands); (c) having current musculoskeletal injuries; (d) using performance-enhancing supplements (e.g., creatine, beta-alanine, anabolic agents); (e) being unable to complete all testing sessions; and (f) having any medical condition that contraindicated maximal exercise. Written informed consent was obtained from all participants. The study received approval from the Ethics Committee of Vasile Alecsandri University, Romania (Decision No. 9/2/09.02.2026) on February 9, 2026. All procedures were conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines. The overall study design and measurement timeline are illustrated in Fig. 1.

Sample size estimation

Sample size was determined a priori using G*Power software (version 3.1.9.7, Universität Düsseldorf, Germany) for repeated measures analysis of variance (ANOVA). Based on the findings of a similar study in competitive athletes [6], which reported an effect size of 0.66 and a statistical power of 0.95, the minimum required sample size was calculated as 9 participants. To account for an anticipated 15% attrition rate (e.g., injury, non-compliance, loss to follow-up) and given the availability of a larger pool of eligible soccer players, a total of 20 participants were recruited.

Randomization and blinding

Participants were randomly allocated to one of three condition sequences using a computer-generated randomization sequence (randomizer.org), and a balanced Latin square design was employed to ensure that each condition appeared equally often in each position (first, second, third) across participants. The randomization sequence was generated by an independent researcher not involved in data collection or analysis. Sequence allocation was concealed using sequentially numbered, opaque, sealed envelopes prepared by the same independent researcher, and envelopes were opened by the intervention deliverer only after completion of the standard warm-up and immediately before delivery of the experimental intervention. Due to the nature of the exercise interventions, participants and the intervention deliverer could not be blinded to condition allocation. However, outcome assessors responsible for administering performance tests and recording measurements were blinded to condition allocation, and data analysts were also blinded until the completion of the primary statistical analysis.

Interventions (i.e. pre-conditioning activities)

All warm-up protocols were delivered by the same certified strength and conditioning coach (with 5 years of experience in team sport settings) to ensure consistency across participants and sessions. Each experimental session followed an identical structure: 5 min of baseline measurements, 5 min of standard warm-up, 5 min of experimental intervention, 2 min of passive rest, and 35–45 min of performance testing. Intervention fidelity was assessed via session attendance records and real-time checklists completed by the intervention deliverer. Adherence was 100%, with all 20 participants completing all three conditions.

All participants completed a standardized 5-minute warm-up prior to the experimental intervention. This consisted of 2 min of light jogging at a self-selected pace followed by 3 min of dynamic movements including high knees, butt kicks, and leg swings (10 repetitions per leg per exercise). Following this standard warm-up, participants were assigned to one of three experimental conditions. In DS + DJ conditioning activity, participants performed DS consisting of two leg swing exercises (anterior-posterior and medial-lateral), each performed for 15 repetitions per leg at a controlled, rhythmic pace (targeting ~ 1 s per phase, equating to ~ 60 bpm, verbally cued by the coach) without ballistic bouncing. Immediately after DS, participants performed three vertical DJ from a plyometric box. DJ height was individualized based on optimal height determined during familiarization sessions, defined as the height that maximized reactive strength index (RSI; jump height divided by ground contact time), and kept consistent across all conditions. For all participants, the optimal height ranged between 30 and 50 cm. Participants were instructed to minimize ground contact time and maximize jump height, dropping from the box with feet shoulder-width apart and performing a maximal vertical jump immediately upon ground contact. In the DJ + DS condition, the order was reversed: participants

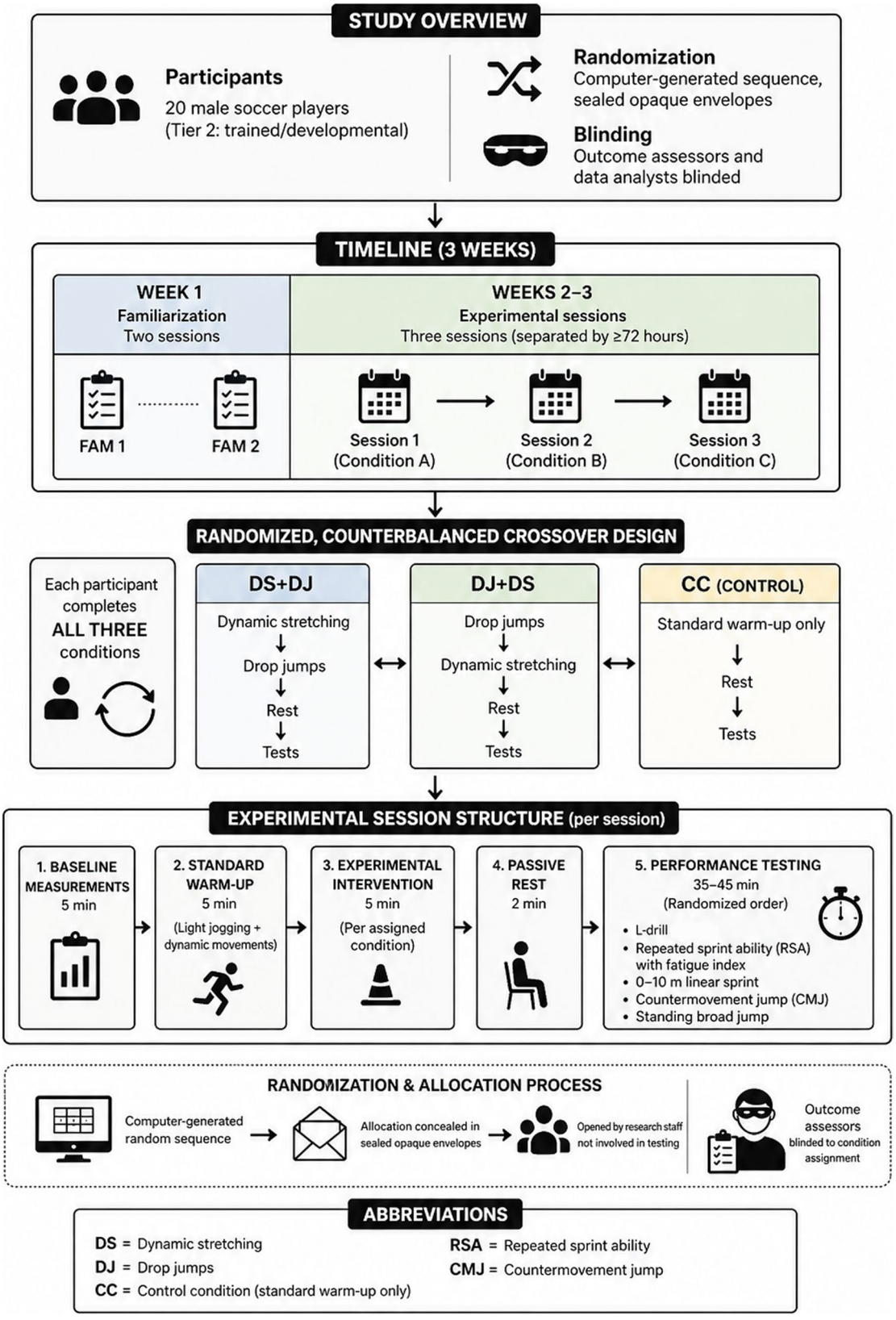

Fig. 1 Experimental study design

first performed three individualized DJ (identical to the DS + DJ condition) followed immediately by the same DS protocol (two leg swing exercises, 15 repetitions per leg per exercise). In the control condition (CC), following the standard warm-up, participants rested passively in a seated position for 5 min with no stretching or plyometric exercises performed.

Following completion of the experimental intervention (i.e., pre-performance conditioning activities), all participants rested passively for 2 min. This rest interval was selected based on previous plyometric PAPE studies reporting optimal acute performance enhancement between 2 and 4 min post-conditioning [19, 20], balancing the trade-off between residual fatigue (shorter rest) and decay of potentiating effects (longer rest). Thereafter, the testing battery was administered in randomized order (determined by a computer-generated sequence for each participant and each session). The testing battery required approximately 35–45 min to complete, with 5 min of passive rest between each test.

Outcomes

L-drill maneuverability

The L-shaped course consisted of three cones. Cone 1 (start/finish) was placed at the base, with Cone 2 positioned 4.6 m directly ahead, and Cone 3 located 4.6 m to the right of Cone 2, forming a 90° angle. Timing gates (Speedlight, Swift Performance, Australia) positioned at the start/finish line recorded total time, with gates set at hip height (0.7 m) to align with the center of mass. Participants began from a stationary two-point staggered stance (front foot placed 0.5 m behind the start gate to prevent premature triggering), sprinted 4.6 m to Cone 2, touched it, and returned to Cone 1. After touching Cone 1, they performed a 180° turn and sprinted back toward Cone 2, rounded it with a 90° turn toward Cone 3, looped around Cone 3 with a 180° turn, and finally sprinted 9.2 m back through the start/finish line [21]. Participants completed two maximal efforts with 2 minutes of passive recovery between attempts. The best (fastest) completion time was recorded for analysis.

Modified repeated sprint ability

The RSA course consisted of a 5 m straight sprint followed by a 45° left cut and a final 5 m sprint to the finish [22]. To control for technique, participants were instructed to perform a side-step cut (i.e., planting the ipsilateral foot and pushing off the outside edge of the foot) and all trials were visually monitored by the same investigator to ensure compliance. Any trial involving a crossover step was repeated after a 2 min rest period. Participants performed six maximal sprints from a standing start. A 25-second passive recovery period was provided between sprints, timed from the moment the participant crossed the finish line of the preceding sprint to the start of the next sprint. Completion time for each sprint was measured using timing gates (Speedlight, Swift Performance, Australia) positioned at the start line (0 m) and the finish line (10 m total distance; 5 m straight + 5 m post-cut). The timing gates were synchronized and set to record to the nearest 0.01 s. Total time was calculated as the sum of all six sprint times. Fatigue index was calculated as secondary outcome: [(Total time / Ideal time) — 1] × 100, where ideal time was the fastest sprint time multiplied by six.

Linear 0-10 m sprint

To assess linear sprint speed, participants performed a 10-meter sprint from a stationary upright two-point staggered start. With the front foot placed 0.5 m behind the start gate to prevent premature triggering, the test was initiated voluntarily by the participant without an auditory cue [23]. Sprint time was recorded using timing gates (Speedlight, Swift Performance, Australia) positioned at the start and 10 m marks, standardized at a height of 0.70 m. Timing commenced when the participant initiated forward movement. Participants completed two maximal attempts with 2 min of passive recovery between trials. The best (fastest) time of the two attempts was recorded.

Countermovement jump test

The bilateral vertical CMJ started with the participant standing upright, hands placed on the hips to eliminate arm swing assistance. Participants performed three maximal CMJ attempts with 30 s of passive recovery between each attempt. The best (highest) jump height of the three attempts was used for analysis. The movement consisted of a rapid, maximal vertical jump preceded by a quick knee bend to approximately 90° of flexion, performed in a single seamless motion. Participants were instructed to keep their limb extended during flight, a key requirement for accurate jump height calculation as body configuration at landing can artificially inflate flight time. An iPhone 15 (iPhone 15, Apple Inc., CA, USA) running the My Jump 3 application (version 3.0.10, Carlos Balsalobre, Madrid, Spain) was used to measure jump height by manually selecting the takeoff and landing frames from recorded video. The same device was used for all measurements across all participants and sessions. Videos were recorded at 240 frames per second using the iPhone 15's slow-motion capture mode, providing a temporal resolution of 4.17 ms between frames. The app computes jump height using the formula ($h = t^2 \times 1.22625$), where h is jump height in meters and t is flight time in seconds. All recordings were made by the same evaluator (a certified athletic training specialist with 5 years of experience in athletic testing and a Master's degree in Sports Sciences) using the same phone, positioned on stationary

tripod at a height of 1 m and a distance of 1.5 m from the participant, ensuring a clear view of the lower limbs. The camera was positioned consistently on the participant's right side, with the optical axis oriented perpendicular to the participant's sagittal plane. This orientation was verified before each testing session using a tripod-mounted bubble level to ensure no tilt. Recordings were taken from the sagittal plane, which offered better visibility for identifying precise takeoff and landing frames than the frontal plane [24].

Standing broad jump distance

Participants performed three maximal horizontal jumps from a standing start with a bilateral takeoff and landing. Arm swing was permitted. Participants were instructed to stick the landing and remain motionless for 2 s. Any trial involving a step, loss of balance, or ground contact behind the heel was repeated once after 30 s of rest. If the repeated trial was also invalid, no score was recorded for that attempt, and the participant proceeded to the next of the three allotted attempts. Landing distance was measured from the takeoff line to the nearest point of contact (heel) using a standardized measuring tape [25]. The best distance among the three attempts (or among valid attempts if fewer than three were successful) was recorded.

Harms assessment

At 24 h post-session, participants received a text message querying current muscle soreness on a 1–10 scale (1 = no soreness, 10 = severe, limiting daily activity) [26]. Additionally, the intervention deliverer documented in real time any musculoskeletal complaints, injuries, or adverse events occurring during any session.

Data analysis

All statistical analyses were conducted using JASP (version 0.19.1.0, Amsterdam, Netherlands) and *Python (version 3.x) with the following packages: NumPy*, *pandas*, *matplotlib*, *seaborn*, *and SciPy.* The significance level was set at $\alpha = 0.05$ for all inferential tests. Data are presented as mean ± standard deviation (SD). Prior to the experimental sessions, the test-retest reliability of each outcome measure was assessed using data collected during the familiarization sessions process. For each outcome variable, the following reliability statistics were calculated: intraclass correlation coefficient (ICC; two-way mixed-effects model with absolute agreement) [27], standard error of measurement (SEM), minimal detectable change (MDC), and coefficient of variation (CV). ICC values were interpreted as follows: poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (> 0.90) [28]. SEM was calculated as $SD \times \sqrt{(1 - ICC)}$. MDC at the 95% confidence level was calculated as $1.96 \times \sqrt{2} \times$ SEM. CV was calculated as (SD / mean) × 100 and averaged across participants. To interpret reliability from the CV, the upper 95% confidence interval limit of the CV estimate was used with the following thresholds: <5.0% = excellent, 5.0–9.9% = good, 10.0–14.9% = moderate, and ≥ 15.0% = poor [29].

For each performance outcome (L-drill time, RSA total time, RSA fatigue index, 0–10 m sprint time, CMJ height, broad jump distance), a two-way repeated measures analysis of variance (ANOVA) was conducted with Condition (DS + DJ, DJ + DS, CC) and Time (pre-warm-up, post-warm-up) as within-subjects factors. The normality of the data was assessed using Shapiro–Wilk tests and visual inspection of Q–Q plots. Sphericity for the Condition factor was assessed using Mauchly's test; if the sphericity assumption was violated, Greenhouse–Geisser corrections were applied. When a significant Condition × Time interaction was detected, simple main effects were examined using Bonferroni-corrected pairwise comparisons. Specifically, pairwise comparisons were conducted to: (a) compare the three conditions at each time point separately, and (b) compare pre- versus post-warm-up within each condition. Effect sizes are reported as partial eta-squared (η^2) for ANOVA results, interpreted as: small (0.01–0.05), medium (0.06–0.13), and large (≥ 0.14) [30]. For pairwise comparisons, Cohen's *d* with 95% confidence intervals is reported, interpreted as: trivial (< 0.20), small (0.20–0.59), medium (0.60–1.19), and large (1.20–1.99) [31]. To examine the relationship between baseline lower-body neuromuscular performance (CMJ height) and PAPE magnitude, Pearson correlation coefficients were calculated between CMJ height (calculated as the average of the three baseline values across experimental conditions) and the change scores (post-test minus pre-test) for each experimental condition relative to control. Correlation coefficients were interpreted as: weak ($r < 0.30$), moderate ($0.30 \leq r < 0.50$), and strong ($r \geq 0.50$) [32]. To assess the validity of the crossover design, period, sequence, and carryover effects were evaluated. Period effects were examined using a two-way mixed-model ANOVA with Period (sessions 1–3) as a within-subject factor and Sequence (condition order) as a between-subject factor. Sequence and carryover effects were assessed by comparing baseline values across sequence groups (one-way ANOVA) and across experimental sessions (repeated-measures ANOVA), respectively. Non-significant results ($p > 0.05$) were considered to support the absence of these effects. As a secondary exploratory analysis, participants were descriptively categorized according to playing position (forwards, $n = 5$; midfielders, $n = 9$; full-backs, $n = 6$). Because the study was not powered for subgroup comparisons and the positional subgroups were very small, these analyses were considered strictly exploratory and hypothesis-generating. Accordingly,

only descriptive statistics and visual inspection of group means were performed, and no inferential statistical tests were conducted. Participants were classified as responders if their performance change (post-test minus pre-test) exceeded the MDC threshold for that outcome (Supplementary Table S1). The number and percentage of responders were tabulated for each condition and outcome.

Results

Participant characteristics and baseline comparisons

A total of 20 male soccer players (age: 20.45 ± 1.65 years; height: 176.59 ± 4.25 cm; body mass: 71.85 ± 4.64 kg; body mass index 23.00 ± 0.41 kg·m^{-2}) completed all three experimental conditions. Mean baseline CMJ height was 41.44 ± 3.96 cm (range: 35.00–48.67 cm). Participants had a mean of 6.60 ± 1.69 years of structured soccer training experience (range: 4–9 years) and completed a mean of 4.20 ± 1.05 structured training sessions per week (range: 3–6 sessions). Muscle soreness at 24 h was minimal across all conditions (mean range 2.1–2.4), with no significant between-condition differences ($p > 0.05$). No participant reported soreness above 4/10, and no injuries or adverse events occurred. Test–retest reliability of all outcome measures ranged from good to excellent, with intraclass correlation coefficients ranging from 0.88 to 0.99 and coefficients of variation ranging from 0.26% (RSA) to 1.23% (linear 10 m sprint). Complete reliability statistics are provided in Supplementary Table S1. Baseline performance values did not differ significantly across the three experimental conditions. One-way repeated measures ANOVA confirmed no baseline differences for L-drill ($p = 0.96$), RSA total time ($p = 0.96$), fatigue index ($p = 0.45$), 10 m sprint ($p = 0.15$), CMJ height ($p = 0.98$), or standing broad jump ($p = 0.90$). Comparisons of the groups based on their z-scores at different time points are presented in Supplementary Figure S1. Supplementary analyses confirmed the validity of the crossover design: no significant sequence effects were observed across the three sequence groups for any outcome (all $p > 0.05$), no carryover effects were detected (all $p > 0.05$), and the Period × Sequence interaction was non-significant for all outcomes (two-way mixed-model ANOVA, all $p > 0.05$). These findings confirm that the observed Condition × Time interactions were not confounded by treatment order, session number, or residual effects.

L-drill maneuverability test

A two-way repeated measures ANOVA revealed a significant Condition × Time interaction ($F = 14.85$, $p < 0.001$, $\eta^2 = 0.43$) (Table 1). DS + DJ produced a significant pre-to-post improvement (Δ = −0.15 s, d = 0.78). Additionally, DS + DJ post-test performance was significantly faster

Table 1 Acute effects of warm-up sequencing on athletic and neuromuscular performance outcomes

Outcome	Condition	Pre-test (M ± SD)	Post-test (M ± SD)	Δ (95% CI)	*p* (interaction)	η^2	Significant pairwise (*p* and d)
L-drill agility (s)	CC	9.13 ± 0.17	9.15 ± 0.17	+ 0.02 [-0.02, + 0.06]	< 0.001	0.43	DS + DJ post < CC post (< 0.001, 0.86); DS + DJ post < DJ + DS post (0.003, 0.79)
	DS + DJ	9.13 ± 0.16	8.98 ± 0.22	-0.15 [-0.21, -0.09]			
	DJ + DS	9.12 ± 0.16	9.13 ± 0.15	+ 0.01 [-0.09, + 0.11]			
Modified repeated sprint ability (s)	CC	32.55 ± 0.59	32.77 ± 0.29	+ 0.02 [-0.08, + 0.53]	0.89	0.004	*None*
	DS + DJ	32.59 ± 0.59	32.79 ± 0.26	+ 0.20 [-0.12, + 0.52]			
	DJ + DS	32.58 ± 0.59	32.80 ± 0.33	+ 0.22 [-0.14, + 0.56]			
Fatigue index (%)	CC	1.77 ± 0.12	3.45 ± 0.29	+ 1.68 [+ 1.51, + 1.84]	0.82	0.01	*None*
	DS + DJ	1.73 ± 0.13	3.47 ± 0.27	+ 1.74 [+ 1.59, + 1.88]			
	DJ + DS	1.71 ± 0.13	3.45 ± 0.25	+ 1.73 [+ 1.60, + 1.85]			
Linear 10 m sprint (s)	CC	2.15 ± 0.06	2.17 ± 0.04	+ 0.02 [-0.008, + 0.04]	0.002	0.35	DS + DJ post < CC post (< 0.001, 1.14); DJ + DS post < CC post (0.03, 0.47)
	DS + DJ	2.14 ± 0.06	2.09 ± 0.09	-0.05 [-0.08, -0.01]			
	DJ + DS	2.11 ± 0.07	2.14 ± 0.08	+ 0.03 [-0.004, + 0.06]			
Countermovement jump (cm)	CC	41.99 ± 4.22	41.92 ± 3.98	-0.06 [-0.65, + 0.52]	0.002	0.28	DS + DJ post > CC post (0.02, 0.26); DS + DJ post > DJ + DS post (0.003, 0.20)
	DS + DJ	41.75 ± 4.21	42.99 ± 4.21	+ 1.23 [+ 0.67, + 1.80]			
	DJ + DS	41.88 ± 4.14	42.10 ± 4.44	+ 0.22 [-0.39, + 0.84]			
Standing broad jump (cm)	CC	231.50 ± 10.76	231.90 ± 10.76	+ 0.40 [-0.95, + 1.75]	0.03	0.18	DS + DJ post > CC post (0.01, 0.23)
	DS + DJ	230.30 ± 10.75	234.50 ± 11.24	+ 4.20 [+ 3.10, + 5.29]			
	DJ + DS	231.70 ± 11.07	233.45 ± 11.73	+ 1.75 [-0.52, + 4.02]			

Abbreviations: CC control condition, *CI* confidence interval, *DJ* drop jump, *DS* dynamic stretching, *M* mean, *SD* standard deviation

Δ: (Post-test)-(Pre-test)

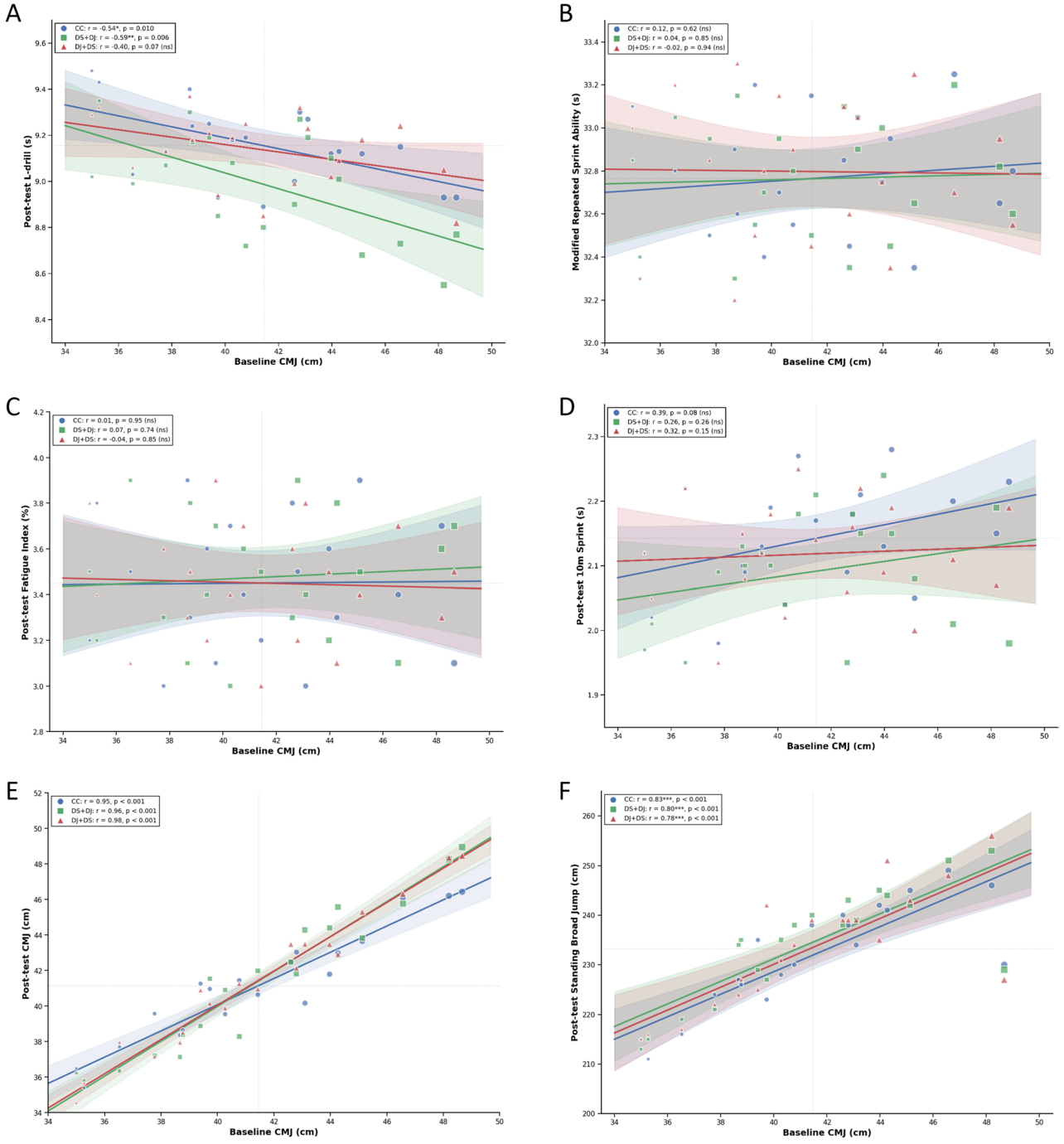

Fig. 2 Correlations between baseline CMJ height and post-test performance for CC, DS+DJ, and DJ+DS. Shaded areas = 95% CI. Abbreviations: CC, control condition; CI, confidence interval; CMJ, countermovement jump; DJ, drop jump; DS, dynamic stretching

than CC post-test (Δ = −0.17 s, d = 0.89) and DJ + DS post-test (Δ = −0.15 s, d = 0.79).

Baseline CMJ height showed significant negative correlations with post-test L-drill performance in the CC (r = -0.54, p = 0.01) and DS + DJ (r = -0.59, p = 0.006) (Fig. 2). These findings indicate that participants with greater lower-body power generally performed faster maneuverability times. Using the MDC threshold of 0.11 s Supplementary Table S1), DS + DJ produced the highest responder rate (55%, n = 11), compared to DJ + DS (20%, n = 4) and CC (15%, n = 3). Exploratory, hypothesis-generating descriptive analyses by playing position showed that full-backs demonstrated the largest improvement following DS + DJ (Δ = −0.17 s), followed by midfielders (Δ = −0.15 s) and forwards (Δ = −0.02 s). Following DJ + DS, forwards showed the greatest performance decrement (Δ

= +0.08 s), whereas full-backs (Δ = +0.01 s) and midfielders (Δ = +0.01 s) exhibited minimal changes.

Modified repeated sprint ability and fatigue index

For both outcomes, the Condition × Time interactions were non-significant (RSA: F = 0.06, $p = 0.89$, $\eta^2 = 0.004$; Fatigue: F = 0.19, $p = 0.82$, $\eta^2 = 0.01$) (Table 1). Correlations between baseline CMJ height and post-test RSA total time (r range: -0.02 to 0.12) and fatigue index (r range: − 0.04 to 0.07) were non-significant for all conditions (all $p > 0.05$) (Fig. 2). Responder rates and position-specific analyses revealed no meaningful differences across conditions or positions.

Linear 10m sprint

A two-way repeated measures ANOVA demonstrated a significant Condition × Time interaction (F = 10.26, $p = 0.002$, $\eta^2 = 0.35$) (Table 1). The DS + DJ resulted in a significant reduction in sprint time from pre-test to post-test (Δ = -0.05 s, d = 0.65). This condition was also significantly faster than the CC (Δ = -0.08 s, d = 1.14). Additionally, the DJ + DS was quicker than the CC (Δ = -0.03 s, d = 0.47).

Baseline CMJ showed non-significant correlations with post-test 10 m sprint performance for all conditions (r range: 0.26 to 0.39, all $p > 0.05$) (Fig. 2). These findings indicate that baseline lower-body power was not significantly associated with 10 m sprint performance following any warm-up sequence. Using the MDC threshold of 0.07 s (Supplementary Table S1), DS + DJ produced responders in 55% of participants ($n = 11$), outperforming DJ + DS (35%; $n = 7$) and CC (20%; $n = 4$). Exploratory, hypothesis-generating descriptive analyses by playing position showed that full-backs demonstrated the largest improvement following DS + DJ (Δ = −0.09 s), followed by forwards (Δ = −0.08 s) and midfielders (Δ = −0.05 s). Following DJ + DS, forwards showed a small improvement (Δ = −0.02 s), whereas full-backs (Δ = +0.01 s) and midfielders (Δ = +0.04 s) demonstrated slight performance decrements.

Countermovement jump

A two-way repeated measures ANOVA showed a significant Condition × Time interaction (F = 7.56, $p = 0.002$, $\eta^2 = 0.28$) (Table 1). The DS + DJ revealed a significant improvement in vertical jump height from pre-test to post-test (Δ = +1.23 cm, d = 0.29). This condition was also significantly greater than CC (Δ = +1.06 cm, d = 0.26) and DJ + DS (Δ = +0.89 cm, d = 0.20).

Positive correlations were observed between baseline CMJ and post-test CMJ values for all conditions (CC: $r = 0.94$; DS + DJ: $r = 0.94$; DJ + DS: $r = 0.97$; all $p < 0.001$) (Fig. 2), indicating that participants with greater baseline power demonstrated higher post-test jump heights. Using an MDC threshold of 1.01 cm (Supplementary Table S1), DS + DJ produced responders in 40% of participants ($n = 8$), outperforming DJ + DS (10%; $n = 2$) and CC (5%; $n = 1$). Exploratory, hypothesis-generating descriptive analyses by playing position showed that forwards demonstrated the largest improvement following DS + DJ (Δ = +1.61 cm), followed by midfielders (Δ = +1.27 cm) and full-backs (Δ = +0.89 cm). Following DJ + DS, forwards showed a small improvement (Δ = +0.20 cm), whereas midfielders (Δ = −0.31 cm) and full-backs (Δ = −0.14 cm) demonstrated slight performance decrements.

Standing broad jump distance

For broad jump distance, the Condition × Time interaction was significant (F = 4.35, $p = 0.03$, $\eta^2 = 0.18$) (Table 1). The DS + DJ demonstrated a significant improvement in jump distance from pre-test to post-test (Δ = +4.20 cm, d = 0.38). Moreover, this condition was significantly greater than CC (Δ = +2.60 cm, d = 0.23).

Positive correlations were observed between baseline CMJ and post-test broad jump performance for all conditions (CC: $r = 0.83$; DS + DJ: $r = 0.80$; DJ + DS: $r = 0.78$; all $p < 0.001$) (Fig. 2), indicating that participants with greater lower-body power also jumped farther. Using an MDC threshold of 6.07 cm (Supplementary Table S1), DS + DJ produced responders in 70% of participants ($n = 14$), outperforming DJ + DS (30%; $n = 6$) and CC (20%; $n = 4$). Exploratory, hypothesis-generating descriptive analyses by playing position showed that full-backs demonstrated the largest improvement following DS + DJ (Δ = +7.0 cm), followed by midfielders (Δ = +6.5 cm) and forwards (Δ = +6.0 cm). Following DJ + DS, midfielders demonstrated the largest improvement (Δ = +1.5 cm), whereas forwards (Δ = +1.0 cm) and full-backs (Δ = +1.0 cm) showed smaller improvements.

Discussion

This study investigated the acute effects of pre-conditioning strategies and sequencing DS and plyometric conditioning (DJ) on athletic and neuromuscular performance outcomes. The primary finding was that performing DS prior to DJs (DS followed by DJ) produced superior improvements in maneuverability, linear sprint speed, vertical jump height, and horizontal jump distance compared to the reverse sequence (DJ followed by DS) and a control warm-up. The DS + DJ improvement exceeded the MDC for L-drill (Δ = -0.15 s > 0.11 s) and CMJ (Δ = +1.23 cm > 1.01 cm), reflecting true meaningful change. For 10 m sprint (Δ = -0.05 s; SEM = 0.03 s; MDC = 0.07 s) and broad jump (Δ = +4.20 cm; SEM = 2.16 cm; MDC = 6.07 cm), changes exceeded the SEM but not the MDC, suggesting a greater than 68% probability that the observed group improvements are genuine. Conversely, the sequencing of DS and DJ did not differentially

influence repeated sprint ability or fatigue index. These results suggest that when the goal is to enhance single-effort impulsive high-intensity actions such as sprinting, jumping, and changing direction, incorporating DS before plyometric conditioning is more effective than the reverse order or standard warm-up alone.

The DS + DJ condition consistently enhanced performance in the L-drill, 10-m sprint, CMJ, and broad jump, with small-to-medium effect sizes (d range = 0.29–0.78).These findings extend prior work by Silva et al. (6), who demonstrated that DS before plyometrics improved late-acceleration linear sprint performance in track athletes (d = 0.30). Our data show that this sequencing advantage generalizes to multi-directional, sport-specific movements in soccer players. Several mechanisms may explain these observations. First, DS increases muscle temperature, reduces passive stiffness, and enhances range of motion, thereby potentially improving the muscle's ability to absorb and return elastic energy during subsequent plyometric and ballistic actions, and thus, increasing propulsive impulse [13, 33]. Performing DS before DJ may therefore prime the stretch-shortening cycle, as increased musculotendinous compliance enhances elastic energy storage and release [34], allowing athletes to better exploit the potentiating effects of DJs. Second, performing plyometrics first (DJ + DS) may induce acute neuromuscular fatigue that masks PAPE, particularly in fast-twitch motor units [35]. This is consistent with the observation that DJ + DS produced small performance decrements in forwards for maneuverability (+ 0.08) and mixed responses in other positions. The transient fatigue hypothesis is further supported by the minimal 24-hour soreness values (2.1–2.4/10), indicating that fatigue was likely neural rather than structural [36]. Notably, neither sequencing condition improved RSA total time or fatigue index. This null finding is important for practitioners: warm-up sequences that effectively enhance single sprints and jumps may not transfer to repeated-sprint contexts where incomplete recovery (25 s) and accumulating fatigue dominate. In agreement, Akgül et al. [37] found that heavy back squat preloading at 85–90% of 1RM failed to improve repeated sprint performance in amateur soccer players ($p = 0.65$, $\eta^2 = 0.01$), further supporting the notion that RSA is resistant to PAPE enhancement due to its high metabolic load. From a practical standpoint, coaches should not expect DS-DJ sequencing to improve repeated-sprint performance; alternative strategies such as heavier conditioning stimuli, longer recovery intervals, or sport-specific priming may be required, and thus requires further investigation.

Baseline CMJ height correlated strongly with post-test performance in all conditions for maneuverability, CMJ, and broad jump. However, baseline CMJ did not moderate the magnitude of PAPE. This contrasts with some previous work suggesting that stronger or more powerful athletes exhibit larger PAPE responses. For instance, Sánchez-Sánchez and Rodríguez-Fernández [38] reported that strength level modulates both the magnitude and time course of PAPE, with stronger athletes benefiting more from high-intensity conditioning protocols. One explanation is that our sample was relatively homogeneous (Tier 2 athletes; CMJ range 35–48.67 cm), limiting the ability to detect moderating effects. Alternatively, the conditioning stimulus (three DJs) may have been submaximal enough to elicit PAPE across a range of power levels without over-fatiguing weaker individuals. The DS + DJ produced the highest proportion of responders across all tests, with the majority of players showing meaningful improvements in maneuverability, sprint speed, jump height, and broad jump distance. In contrast, responder rates for the DJ + DS and CC were lower. These data indicate that while DS + DJ is effective at the group level, individual responses vary considerably, with a meaningful minority of players failing to benefit from either sequencing strategy. Rest interval length is another pertinent factor, as Cormier et al. note that weaker athletes may require longer recovery to optimize PAPE [39], whereas our fixed 2-minute rest may have been insufficient for some individuals. Factors such as baseline strength, fiber type composition, and habitual training status [40, 41] may influence who responds optimally to DS + DJ sequencing. Full-backs showed the largest improvements in agility and broad jump following DS + DJ, whereas forwards responded best in vertical jump height. Following the reverse sequence (DJ + DS), forwards demonstrated a performance decrement in agility, while midfielders and full-backs were largely unaffected. These preliminary observations may relate to positional differences in muscle fiber type distribution, stretch-shortening cycle utilization, or habitual movement patterns [42–44]. From a practical standpoint, practitioners should consider monitoring individual responses to warm-up protocols in relation to the MDC to identify meaningful changes in performance and, where feasible, individualize sequencing strategies based on observed responses. Regarding the exploratory position-specific findings, the small subgroup sizes preclude definitive conclusions, and these observations should be considered strictly hypothesis-generating. Replication in larger, adequately powered, position-stratified studies is required before position-specific recommendations can be made.

Limitations

This study has several limitations that should be acknowledged. First, the CC used passive rest rather than an active control, so comparisons with the control may reflect general activity effects rather than sequencing order. However, the primary comparison between DS + DJ and DJ + DS (matched for total work, differing only in order) shows that sequencing itself drives the observed improvements. Future studies should include an active control group. Second, the sample consisted exclusively of male, Tier 2 soccer players. Generalizability to female athletes, elite professionals, youth players, or older players is unknown and requires further investigation. Third, we used a single conditioning stimulus (three DJs). Different plyometric volumes, intensities, or rest intervals might yield different sequencing effects. Fourth, the supplementary position-specific analyses were exploratory and underpowered due to the very small subsample sizes. No inferential statistical testing was performed for these analyses, and the descriptive findings should be interpreted with extreme caution. We explicitly emphasize that these observations are hypothesis-generating. Any position-specific conclusions would require replication in larger, adequately powered, position-stratified trials before they can be considered clinically or practically meaningful. Fifth, although outcome assessors were formally blinded to condition allocation, the visibly different warm-up protocols meant that complete blinding could not be guaranteed. Assessors may have inferred the intervention condition from observing participants immediately before testing, introducing the potential for detection bias despite standardized outcome measurements. Future studies should use independent assessors who remain isolated from the intervention procedures or employ automated outcome recording where feasible. Sixth, we did not directly measure neuromuscular mechanisms (e.g., electromyography, tendon stiffness, or twitch interpolation), limiting our ability to make causal inferences about the relative contributions of PAPE versus fatigue. Seventh, although test order was randomized, PAPE responses are highly time-dependent, and we did not record the exact elapsed time between completion of the conditioning intervention and each individual performance test. Because the testing battery lasted approximately 35–45 min, participants inevitably completed some assessments substantially later than others. Consequently, the magnitude of potentiation may have partially decayed before later tests were performed, potentially attenuating the observed effects and contributing to variability across outcomes. Although randomization of test order helped distribute this potential bias across conditions, the absence of standardized or recorded intervention-to-test intervals limits precise interpretation of the temporal characteristics of the PAPE response. Future studies should standardize, record, and report these elapsed times for each performance assessment. Eighth, we did not assess baseline muscle stiffness, range of motion, or muscle temperature, which could have provided mechanistic insight into why DS + DJ was superior. Ninth, we did not collect objective performance indicators such as maximal strength, relative strength, RSI, or sprint-performance profiles beyond years of training and weekly session frequency. As PAPE responses are known to be influenced by an athlete's strength and reactive qualities [40], the absence of these measures limits both the interpretation of the mechanisms underlying the observed responses and the generalizability of our findings to athletes with different performance characteristics. Although CMJ height was included as a proxy for lower-body power, it does not directly assess maximal strength or reactive strength, both of which may independently moderate responses to warm-up sequencing. Future studies should incorporate these objective performance measures to better characterize participants and identify potential moderators of sequencing effects. Tenth, although we tested for period, sequence, and carryover effects and found no evidence of such effects, we acknowledge that the statistical power for these supplementary analyses was limited by the sample size. Nevertheless, the balanced Latin square design, the 72-hour washout period between sessions, and the absence of baseline differences across conditions collectively support the internal validity of the crossover design. Future crossover studies with larger sample sizes may consider including these analyses as primary rather than supplementary tests. Finally, DJ execution was verified only visually by the coach. We did not use force platforms or 2D motion analysis to objectively measure ground contact time or RSI. Future studies should employ such tools to ensure consistent execution and to quantify the conditioning stimulus more precisely.

Conclusion

Among competitive amateur soccer players, performing DS before DJs acutely improves maneuverability, 10-m sprint speed, CMJ height, and standing broad jump distance compared to the reverse sequence (DJ + DS) or a control warm-up alone. This sequencing effect does not generalize to repeated sprint ability, which was unchanged by either warm-up strategy. Therefore, coaches and practitioners can consider a pre-conditioning strategy consisting of DS + DJ sequencing when preparing players for single-effort high-intensity actions (e.g., sprinting, jumping, changing direction), while recognizing that repeated sprint ability requires distinct warm-up or training interventions. Practitioners should therefore consider separate conditioning strategies for repeated-sprint contexts,

such as short sprints with incomplete recovery during warm-up.

Supplementary Information

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Supplementary Table S1.

Supplementary Figure S1

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Authors' contributions
Conceptualization, S.Ö., B.A., D.H.A., M.B., I.B., Y.Ş., M.I., M.A. (Mohammad Alghosi), M.A. (Mohammad Alimoradi), and T.D.; methodology, S.Ö., B.A., D.H.A., M.B., I.B., Y.Ş., M.I., M.A. (Mohammad Alimoradi), and T.D.; software, S.Ö. and M.A. (Mohammad Alimoradi); validation, B.A., D.H.A., M.B., I.B., Y.Ş., M.I., and M.A. (Mohammad Alghosi); formal analysis, S.Ö., M.A. (Mohammad Alimoradi), and T.D.; investigation, S.Ö., B.A., D.H.A., M.B., I.B., Y.Ş., M.I., and M.A. (Mohammad Alghosi); resources, S.Ö., B.A., D.H.A., M.B., I.B., Y.Ş., and M.I.; data curation, S.Ö., M.A. (Mohammad Alimoradi), and T.D.; writing—original draft preparation, S.Ö., B.A., D.H.A., M.A. (Mohammad Alimoradi), and T.D.; writing—review and editing, all authors; visualization, S.Ö., M.A. (Mohammad Alimoradi), and T.D.; supervision, B.A., M.B., M.A. (Mohammad Alimoradi), and T.D.; project administration, S.Ö., B.A., D.H.A., and M.A. (Mohammad Alimoradi). All authors have read and agreed to the published version of the manuscript.

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Data availability
The data that supports the findings of this study are available in the Zenodo data repository at https://doi.org/10.5281/zenodo.20272504.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Vasile Alecsandri University, Romania (Decision No. 9/2/09.02.2026) on February 9, 2026, and written informed consent was obtained from all participants prior to enrollment.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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