Research Square

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Acute Effects Of Short-Term Static, Active Isolated, And Dynamic Stretching Protocols On Explosive Power and Hamstring Flexibility in Active Males

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Abstract

Stretching is commonly used in warm-up routines, yet evidence regarding its acute effects on flexibility and explosive performance remains mixed, particularly when considering technique, duration, and tempo. This study compared the immediate and short-term effects of static stretching (SS), active isolated stretching (AIS), and dynamic stretching (DS) protocols with different tempos and durations on hamstring flexibility and countermovement jump (CMJ) performance in active males. Thirty healthy, physically active men (22–25 years; body mass index (BMI) < 30 $kg \cdot m^{-2}$), each with at least two years of resistance-training experience, completed a randomized cross-over design involving six stretching conditions: SS (30-s passive stretch), AIS (30-s total active contractions), and four DS variations combining tempo (100 or 150 beats/min) and duration (30 or 75s): DS100/30, DS150/30, DS100/75, and DS150/75. Hamstring flexibility was assessed using the Passive Straight-Leg Raise test, and CMJ height and power were measured using a Swift Performance Speed Mat. Measurements were obtained before stretching and immediately, 5 minutes, and 10 minutes afterward. Repeated-measures ANOVA and paired t-tests were used ($p < .05$). All stretching protocols significantly improved flexibility ($p < .05$), with the greatest improvements following DS150/30 and AIS. CMJ height and power increased at all post-stretch time points for DS150/30, AIS, and DS100/30 ($p < .05$), whereas longer DS durations (75 s) did not enhance performance. Short-duration, high-tempo dynamic stretching (150 bpm, 30 s) produced the most effective acute improvements in flexibility and explosive power. These findings emphasize the importance of stretch duration and tempo when designing warm-up routines.

Introduction

One of the most important and essential elements of athletic warm-up regimens that improve performance and flexibility is stretching (1). The relationship between various stretching modalities and their influence on physical capabilities, particularly explosive power, remains a topic of ongoing investigation and debate (2). Stretching can be categorized in different formats, static stretching (SS), active isolated stretching (AIS) and dynamic stretching (DS), the later as well as AIS is said to confer its own advantages with specific patterns of use and accompanying mechanisms (2).

Due to methodological differences in stretching duration, intensity, muscle group selection, and inclusion in full warm-up routines, results regarding the acute effects of stretching on performance remain inconsistent and sometimes contradictory despite decades of research (3–5). This inconsistency highlights the need for additional standardized studies evaluating various stretching techniques in similar experimental settings. SS, which involves holding a muscle in a lengthened position for a specific period of time, has been extensively studied within the context of sports performance. While traditionally used to improve flexibility, prolonged static stretching (> 60 s) has been associated with temporary reductions in explosive performance metrics such as CMJ height (4, 6). Conversely, short-duration SS (≤ 30 s) appears to produce negligible decrements and may therefore be incorporated into warm-up routines without impairing subsequent performance (7). Recent systematic reviews have further demonstrated that brief static stretches (30–60 s per muscle group), when integrated into a complete

warm-up routine involving aerobic and dynamic activities, do not meaningfully impair strength or jump performance (4, 5). Therefore, the frequently mentioned disadvantages of static stretching can be exaggerated, especially when done at the right time and for a short period.

Meanwhile, AIS has attracted increasing interest for its unique contraction–relaxation erntechnique, which may enhance range of motion (ROM) without the potential inhibitory effects sometimes observed with static stretching (8). Emerging evidence also suggests that AIS may help maintain or even enhance explosive performance when integrated into warm-up routines (8). However, studies examining its acute effects on athletic performance remain scarce and inconsistent. For instance, Waqqash et al. (9) reported reductions in jump performance following AIS protocols exceeding 60 seconds in total duration. Such findings suggest that total stretch duration may be a critical factor. In order to bridge this gap, the present study standardized AIS duration to 30 seconds to ensure comparability with short SS protocols and to isolate the potential influence of AIS on explosive performance.

Furthermore, DS has gained substantial support as a superior approach for enhancing both flexibility and performance (2, 10). DS is characterized by continuous movements that actively engage muscles through sport-specific ranges of motion, DS increases muscle temperature, neural activation, and potentiation of the stretch-shortening cycle (SSC) prior to explosive activity (10, 11). However, the literature shows considerable variability, particularly in DS protocol design regarding tempo and application time, with few studies explicitly controlling these factors. Fletcher demonstrated that DS performed at 100 beats per minute (bpm) significantly improved CMJ and drop-jump performance compared with 50 bpm, highlighting movement tempo as an important yet underexplored determinant of effectiveness (12). Accordingly, the present study incorporates DS protocols performed at two controlled tempos (100 and 150 bpm) and two durations (30 and 75 s) to systematically evaluate their combined effects on flexibility and explosive power.

In addition, few studies have examined how long any performance effects of stretching persist after completion. To explore potential time-dependent recovery or potentiation, this study assessed CMJ performance immediately after, and at 5- and 10-minutes post-stretching, following the methodological rationale of Torres et al. (13) and the time-course observations reported by Konrad and Tilp (14).

The hamstring muscle group was chosen as the reference muscle because of its importance for lower-limb power generation, and well-documented relationships with flexibility deficits, injury risk, and decreases in muscular performance (15, 16). This emphasis carries great applied importance for athletes involved in sprinting and jumping sports. Therefore, strength and conditioning coaches need clear proof on whether stretching modality, duration, and movement tempo might boost explosive performance without reducing power output during warm-ups before training or competition.

To the best of our knowledge, no previous study has simultaneously compared SS, AIS, and multiple DS protocols differing in both tempo and stretch-bout duration while also examining time-dependent changes in performance. Therefore, this study was designed to address these gaps. Based on the evidence summarized above, it was hypothesized that (i) dynamic stretching, particularly the short-

duration high-tempo protocol (DS150/30), would lead to the greatest acute improvement in countermovement jump performance compared with SS and AIS, and (ii) all stretching techniques would enhance hamstring flexibility, with AIS and short-duration dynamic stretching expected to produce the most pronounced gains.

Methods

Experimental Approach to the Problem

This study employed a randomized, counterbalanced, within-subject crossover design to examine the acute effects of different stretching modalities on hamstring flexibility and explosive performance. Each participant completed seven experimental sessions (six stretching conditions and one control condition) separated by at least 72 hours to minimize residual fatigue and carryover effects (Fig. 1). The independent variables were stretching modality (static stretching, active isolated stretching, dynamic stretching), movement tempo (100 vs. 150 beats·min^{-1}), and stretch duration (30 vs. 75 s). The dependent variables were hamstring ROM assessed via passive straight-leg raise and CMJ height and power output. This design allowed direct comparison of modality-, tempo-, and duration-specific effects to test the hypothesis that short-duration, high-tempo dynamic stretching would produce superior acute improvements in explosive performance.

Subjects

A total of 30 healthy, recreationally active male participants volunteered for this study. Their mean ± SD characteristics were as follows: age = 23.60 ± 0.40 years; height = 178.02 ± 8.02 cm; body mass = 76.24 ± 7.24 kg; and BMI = 23.23 ± 2.23 kg·m^{-2}. All participants had been engaging in regular exercise for at least two years and had a BMI below 30 kg·m^{-2}. Participants were classified as low-risk according to Physical Activity Readiness Questionnaire (PAR-Q+) and the American College of Sports Medicine health risk stratification guidelines. All individuals provided written informed consent prior to participation. (17, 18) The study was approved by the **Marmara University Faculty of Medicine Clinical Research Ethics Committee (Approval date and number: 02 April 2021 / 09.2021.283)** and all procedures were conducted in accordance with the Declaration of Helsinki.

An a priori power analysis was conducted based on variance estimates reported in similar repeated-measures ANOVA studies (19, 20). Assuming a repeated-measures design (within factors), a statistical power of 0.95 and an alpha level of 0.05, the required sample size was calculated as 25 participants. To account for potential dropouts and ensure adequate statistical power, 30 recreationally active males were ultimately recruited for the study.

Procedures

All sessions were implemented at the same time of day under controlled environmental conditions to minimize circadian rhythm and environmental influences on performance and flexibility outcomes. Participants were instructed to maintain consistent dietary habits, avoid caffeine, alcohol, and strenuous exercise for at least 24 hours prior to testing, and ensure adequate sleep.

Warm-up and Testing Sequence

The experimental protocol consisted of seven sequential phases, as illustrated in Fig. 1. Each participant performed the procedures in the same order and under identical environmental conditions to ensure consistency.

Stretching Protocols: Seven stretching conditions were applied in randomized order: a control condition (CON), SS, AIS, and four DS variations differing in duration and tempo (Table 1). All stretching techniques targeted the hamstring muscle group. The SS protocol was performed in the supine position; with the pelvis stabilized and the opposite leg extended on the floor, the investigator passively raised the test leg into hip flexion with the knee fully extended until the participant reached the point of mild discomfort, and this position was maintained for 30 seconds before switching sides (Fig. 2A). Following this, the AIS protocol followed the standard contraction–relaxation sequence: participants lay supine and actively lifted the test leg into hip flexion, briefly holding the terminal position for 2 seconds before returning to the starting position; this sequence was repeated 15 times per leg and the three-step AIS sequence is shown in Fig. 2B1-B3.

Table 1
Description of the seven stretching protocols applied in random order.

Protocol	Description
CON	No stretching
SS	30 s per leg, static stretching in the supine position
AIS	15 repetitions per leg, each with a 2 s active contraction
DG30/100	Dynamic stretching for 30 s at 100 bpm
DG30/150	Dynamic stretching for 30 s at 150 bpm
DG75/100	Dynamic stretching for 75 s at 100 bpm
DG75/150	Dynamic stretching for 75 s at 150 bpm

Table note

CON = Control; SS = Static Stretching; AIS = Active Isolated Stretching; DG30/100 = Dynamic Stretching for 30 s at 100 bpm; DG30/150 = Dynamic Stretching for 30 s at 150 bpm; DG75/100 = Dynamic Stretching for 75 s at 100 bpm; DG75/150 = Dynamic Stretching for 75 s at 150 bpm.

The DS protocols consisted of rhythmic forward straight-leg swings performed through each participant's active range of motion while maintaining full knee extension as depicted in Fig. 2C. Four DS variations were implemented to systematically manipulate tempo and duration: 30 seconds at 100 beats/min (DG30/100), 30 seconds at 150 beats/min (DG30/150), 75 seconds at 100 beats/min (DG75/100), and 75 seconds at 150 beats/min (DG75/150). Movement tempo was precisely controlled using a Musedo MT-40 digital metronome (± 0.3% accuracy).

Hamstring flexibility was assessed using the passive straight-leg raise (PSLR) test with a Baseline 360° goniometer following standardized procedures (21). The axis was aligned over the greater trochanter, the stationary arm with the mid-axillary line of the trunk, and the movable arm with the lateral femoral epicondyle. All flexibility assessments were conducted by the same investigator to ensure measurement consistency. CMJ height and power output were recorded using a Swift Performance Speed Mat 260 (Swift Performance, Brisbane, Australia), which derives jump metrics from flight time (22). Participants performed three maximal CMJs with hands on hips, separated by ~ 10 seconds, and the highest value was used for analysis. No rest, stretching, or additional movements were permitted between attempts (Fig. 2).

The Perceived Recovery Status scale (23) was administered immediately before each CMJ test to quantify subjective readiness. Post-stretch assessments of PSLR and CMJ were obtained immediately, and again at 5 and 10 minutes following each intervention, in accordance with procedures commonly used to evaluate short-term potentiation and recovery responses (13, 14).

Statistical Analysis

All analyses were conducted using IBM SPSS Statistics version 24. Data normality was tested using the Kolmogorov–Smirnov test, along with Skewness and Kurtosis indices. Descriptive statistics (mean: ± SD) were computed for all variables. The effects of stretching type and time were examined via two-way repeated-measures ANOVA (protocol × time). When significant effects were detected, paired-samples t-tests and Tukey HSD post hoc tests were performed. Statistical significance was set at $p < 0.05$.

Results

All 30 participants completed all experimental sessions and were included in the final analyses. No participants were excluded or lost to follow-up after randomization. The immediate post-stretching assessments indicated that all stretching protocols produced statistically significant improvements in hamstring ROM compared to baseline measurements ($p < 0.05$). Among the various protocols, AIS yielded a 5.55% improvement, whereas SS resulted in a more modest 3.22% increase. When considering the dynamic stretching protocols, DS 150/30 elicited the greatest enhancement, with a 7.35% increase in flexibility. DS 100/30 also produced a significant but smaller improvement of 4.34%. Notably, the longer-duration dynamic stretching protocols (DS 100/75 and DS 150/75) enhanced flexibility by 6.56% and

6.67%, respectively; however, these longer durations demonstrated diminishing returns compared to their shorter-duration counterparts.

Performance Outcomes

In the realm of performance, CMJ metrics revealed the most substantial enhancements with the DS 150/30 protocol, resulting in an impressive increase of 11.39% in jump height and a 7.93% increase in mean power output. AIS also demonstrated notable efficacy with a 7.61% increase in jump height and a corresponding 4.81% increase in mean power output. Conversely, the DS 100/30 protocol provided a modest improvement of 1.81% in jump height and 1.26% in mean power output. Interestingly, extending the duration of the dynamic stretching exercises led to a decline in performance outcomes, as indicated by the DS 100/75 and DS 150/75 protocols, which resulted in decreases of − 0.20% and − 1.43% in jump height, and declines of − 0.25% and − 1.12% in mean power output, respectively. A comprehensive summary of these results is provided in Tables 2 and 3.

Table 2
Changes in Flexibility and CMJ Performance (Pre vs. Post-Test)

Protocol	Flexibility %	CMJ %	Mean Power %	Peak Power %
SS	+ 3.22	+ 0.77	+ 0.72	+ 0.20
AIS	+ 5.55	+ 7.61	+ 4.81	+ 2.19
DS 100/30	+ 4.34	+ 1.81	+ 1.26	+ 0.58
DS 150/30	+ 7.35	+ 11.39	+ 7.93	+ 3.34
DS 100/75	+ 6.56	−0.20	−0.25	−0.08
DS 150/75	+ 6.67	−1.43	−1.12	−0.46

SS = Static Stretching; AIS = Active Isolated Stretching; DG30/100 = Dynamic Stretching for 30 s at 100 bpm; DG30/150 = Dynamic Stretching for 30 s at 150 bpm; DG75/100 = Dynamic Stretching for 75 s at 100 bpm; DG75/150 = Dynamic Stretching for 75 s at 150 bpm.

Table 3
CMJ Performance at 5th and 10th min. Post-Stretching

Protocol	% (5th min.)	% (10th min.)
SS	+ 1.51%	+ 1.09%
AIS	+ 8.77%	+ 4.80%
DS 100/30	+ 4.02%	+ 4.06%
DS 150/30	+ 12.21%	+ 13.17%
DS 100/75	+ 1.30%	+ 1.40%
DS 150/75	−0.49%	+ 1.201%

SS = Static Stretching; AIS = Active Isolated Stretching; DG30/100 = Dynamic Stretching for 30 s at 100 bpm; DG30/150 = Dynamic Stretching for 30 s at 150 bpm; DG75/100 = Dynamic Stretching for 75 s at 100 bpm; DG75/150 = Dynamic Stretching for 75 s at 150 bpm.

Discussion

This crossover study demonstrates that brief, high-tempo dynamic stretching (DS 150/30) elicited the most pronounced acute improvements in explosive performance among the tested conditions. Specifically, CMJ height and power output increased by approximately 7–8% compared to the CON, while AIS produced smaller but meaningful enhancements of around 4–5%. In contrast, long-duration dynamic stretching protocols (75 seconds) resulted in trivial or slightly negative changes in CMJ metrics, suggesting that both tempo and duration are critical determinants of acute neuromuscular readiness. All stretching protocols significantly improved hamstring flexibility, with the largest increase observed following DS 150/30 and AIS.

These findings align with previous meta-analytic and experimental evidence indicating that short-duration static stretching (< 60 s per muscle) produces negligible or trivial reductions in maximal strength and power, whereas longer durations impair explosive performance. (4, 24, 25) Similarly, dynamic stretching is generally advantageous or at least not detrimental when performed before activities requiring maximal effort (2, 26, 27). The present findings further emphasize that the tempo of dynamic stretching is a determinative factor in identifying its acute outcomes. In support of this notion, Paradisis et al. (28) demonstrated that faster, rhythmically controlled dynamic movements enhance jump performance more effectively than slower movements. This pattern is consistent with our data, in which a tempo of 150 bpm produced superior CMJ outcomes compared with 100 bpm and longer stretching durations.

The effects of AIS observed in the present study contribute to clarifying the conflicting evidence in the literature. Prior studies have reported that AIS lasting longer than 60 seconds per muscle may lead to

performance declines (8). In contrast, our 30-second AIS protocol improved CMJ height and power, suggesting that the acute effects of AIS follow a time-dependent pattern similar to that observed for static stretching. This supports the hypothesis that AIS, when performed briefly, may enhance range of motion without inducing the neural inhibition or musculotendinous relaxation commonly seen after prolonged stretching.

The superior acute responses to AIS in the present study may also be explained by its unique physiological mechanisms. Unlike static stretching, AIS involves repetitive isotonic contractions that enhance local blood flow, oxygenation, and nutrient exchange, thereby improving tissue elasticity and neuromuscular efficiency (2, 5). These active contractions may facilitate reciprocal inhibition of antagonist muscles, promoting safer and more specific elongation of the targeted muscle groups. Furthermore, the brief stretch duration (~ 2 s per repetition) prevents excessive muscle spindle activation and minimizes the stretch reflex, maintaining muscle excitability and power output. Controlled breathing during AIS may further reduce fatigue by limiting lactate accumulation and promoting parasympathetic activation, ultimately contributing to the enhanced flexibility and explosive performance observed in the current study (14).

The superior performance observed following DS 150/30 likely reflects a combination of neural and mechanical mechanisms. Rapid, brief dynamic movements enhance muscle temperature, elevate motoneuron excitability, and improve synchronization of motor unit recruitment. They may also potentiate the stretch-shortening cycle (SSC) by increasing elastic energy storage and neural facilitation, mechanisms consistent with post-activation performance enhancement (29). Conversely, extended or low-tempo dynamic stretching may elevate metabolic cost, reduce musculotendinous stiffness, and cause viscoelastic creep, thereby impairing power output and delaying the rate of force development.

The temporal analysis across the 1-, 5-, and 10-minute post-stretching intervals revealed that the performance enhancements induced by DS 150/30 persisted for at least 10 minutes. This time course supports the functional window of potentiation described in previous studies (13, 14). Such persistence underscores the practical relevance of high-tempo dynamic stretching, which appears to sustain explosive readiness during the transition from warm-up to performance. In contrast, the performance decrements following long-duration dynamic stretching likely reflect transient reductions in stiffness and decreased neural activation, possibly due to excessive musculotendinous relaxation.

From a practical standpoint, these results suggest that pre-performance warm-ups should incorporate brief (~ 30 s) high-tempo (~ 150 bpm) dynamic stretching targeting the primary muscles engaged in explosive movements. When dynamic stretching is not feasible, short-duration AIS (~ 30 s) may serve as an effective alternative without compromising performance. However, long-duration dynamic stretching (≥ 75 s) should be avoided immediately prior to maximal efforts, as it may reduce jump height and power output. To optimize benefits, warm-ups should be completed within approximately 10 minutes before competition to capitalize on the temporal window of potentiation observed in this study.

The main advantages of this study are the within-subject comparisons, standardized testing conditions, and randomized crossover design with 72-hour intervals, which reduced interindividual variability. Internal validity was enhanced by the use of proven measurement tools in uniform environmental conditions for all flexibility and performance assessments. However, several limitations should be considered. Because the participant sample was limited to young, recreationally active males, generalization to females, older adults, or elite athletes is limited. Furthermore, the complexity of sport-specific explosive movements may not be fully captured by CMJ assessment in a controlled laboratory setting, limiting ecological validity. Future studies should assess individual variability between responders and non-responders, measure changes in muscle-tendon properties in relation to performance indicators and examine chronic adaptations resulting from repeated exposure to different stretching procedures.

In conclusion, the present findings demonstrate that the short-duration high-tempo dynamic stretching protocol (DS150/30) produced the most substantial acute enhancement in explosive performance, increasing CMJ height and power by approximately 7–8% compared with the CON. AIS elicited moderate but positive effects, whereas long-duration dynamic stretching (≥ 75 s) failed to improve or slightly reduced CMJ performance. These results confirm that stretch duration and movement tempo are critical determinants of neuromuscular readiness and explosive performance. Additionally, all stretching techniques improved hamstring flexibility, with AIS and short-duration dynamic stretching producing the largest gains. Overall, implementing DS150/30 during the final minutes of a warm-up may effectively enhance acute power output while avoiding the potential performance-reducing effects associated with longer stretching durations.

Practical Applications

Strength and conditioning practitioners should incorporate brief, high-tempo dynamic stretching (~ 30 s at ~ 150 beats·min^{-1}) during the final phase of warm-up routines when explosive performance is required. This approach enhances jump performance and flexibility without reducing power output. Prolonged dynamic stretching (≥ 75 s per muscle group) should be avoided immediately before maximal efforts, as it may attenuate explosive performance. When dynamic stretching is not feasible, short-duration active isolated stretching (~ 30 s total) can be used to improve range of motion without compromising neuromuscular readiness. To maximize potentiation effects, explosive activities should be performed within approximately 10 minutes after completing the warm-up.

Abbreviations

AIS Active Isolated Stretching

BMI Body Mass Index

CMJ Countermovement Jump

CON Control Condition

DS Dynamic Stretching

PAR-Q+ Physical Activity Readiness Questionnaire for Everyone

PSLR Passive Straight-Leg Raise

ROM Range of Motion

SSC Stretch–Shortening Cycle

SS Static Stretching

Declarations

Ethics approval and consent to participate

The study was approved by the Marmara University Faculty of Medicine Clinical Research Ethics Committee (Approval date and number: 02 April 2021 / 09.2021.283). All participants provided written informed consent prior to participation. All procedures were conducted in accordance with the Declaration of Helsinki.

Consent for publication

Written informed consent for publication of the participant's images was obtained.

Availability of data and materials

The datasets generated and/or analysed during the current study are available from the corresponding author (Yeliz Pınar) upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

MS, YP, EA, and SP contributed to the conceptualization of the study. YP developed the methodology. MS and YP were responsible for software. EA and SP conducted the formal analysis. SP and MS carried out the investigation. MS, EA, and SP curated the data. EA performed the visualization. YP was responsible

for supervision and validation. YP and SB managed project administration. EA, YP, MS, and SP wrote the original draft. SP, EA, MS, and YP reviewed and edited the manuscript. All authors read and approved the final version of the manuscript.

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Figures

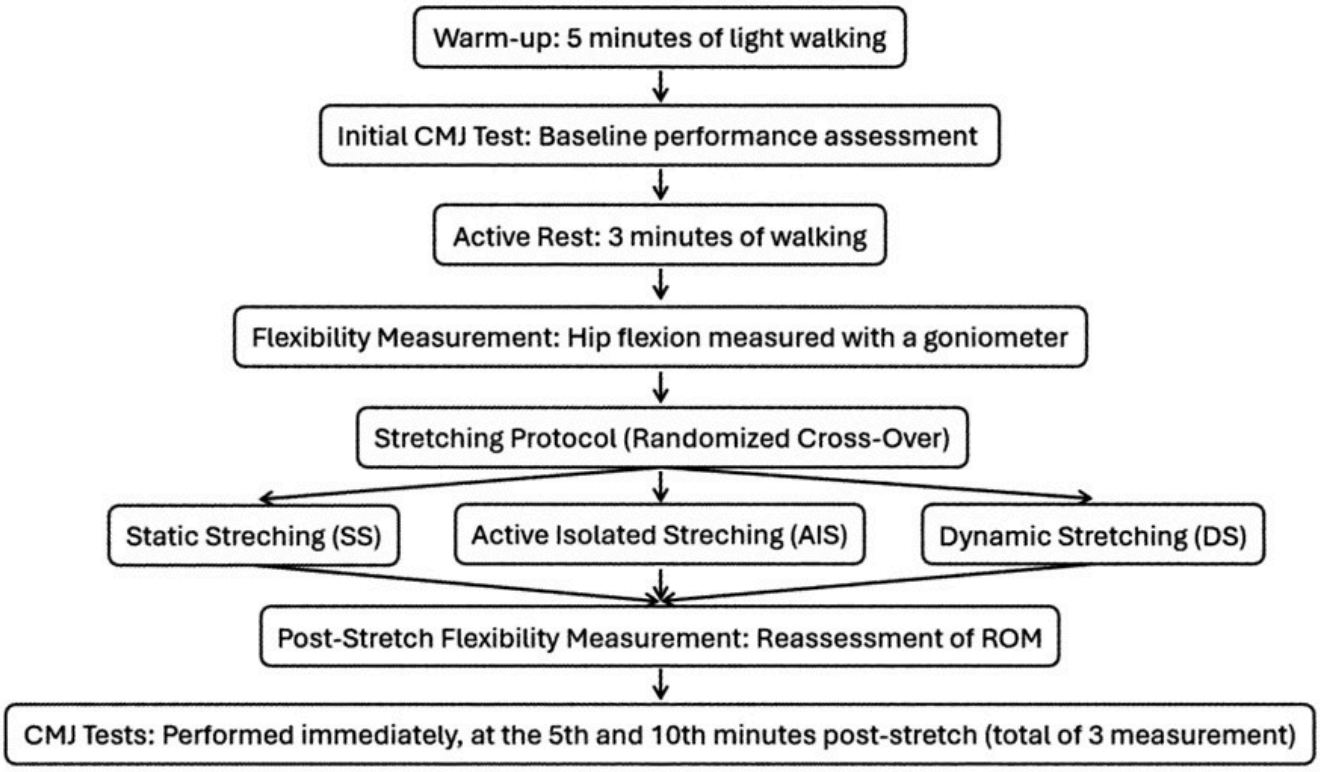


Figure 1

Warm-up and testing sequence followed during each experimental session. Flowchart of the experimental protocol showing warm-up, baseline testing, stretching interventions, and post-stretch assessments. CMJ = countermovement jump; ROM = range of motion.

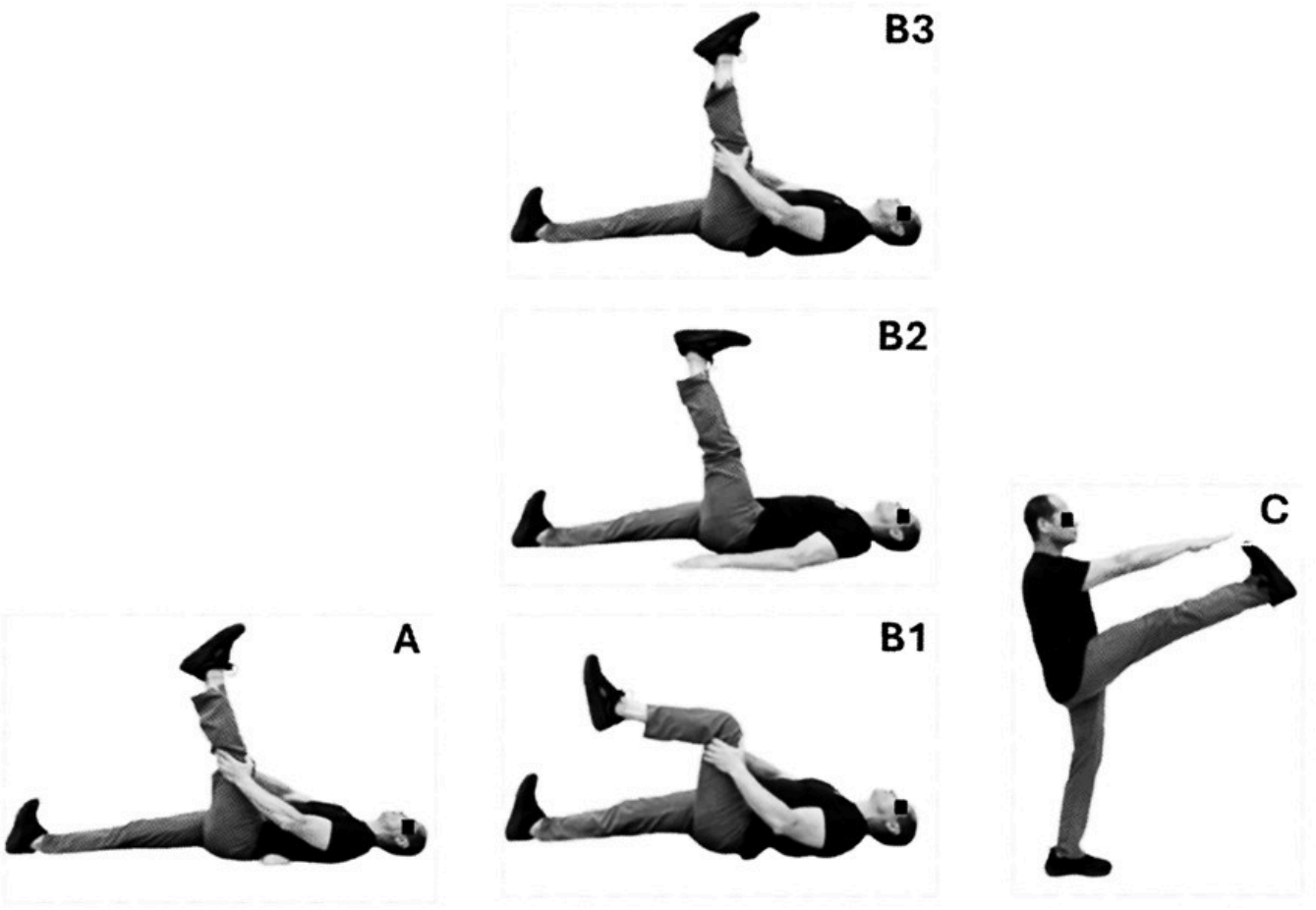


Figure 2

Demonstration of the stretching procedures applied in the study. (A) Static stretching (SS): Passive hip-flexion stretch performed in the supine position with the knee fully extended. (B1) AIS starting position; (B2) AIS active contraction position; (B3) AIS end-range stretch position. (C) Dynamic stretching (DS): Forward straight-leg swing performed through the active range of motion with tempo controlled by a digital metronome.