ORIGINAL ARTICLE

Acute effects of inter-set static stretching on hamstring strength and range of motion (ROM)

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ABSTRACT

Purpose: Inter-set stretching has been proposed as a strategy to influence subsequent performance during resistance exercise, yet its acute effects remain controversial. While some studies suggest potential benefits for flexibility and range of motion (ROM), concerns persist regarding possible impairments in strength output and total training volume (TTV). Methods: Seventeen trained males were randomly assigned to one of two protocols: (a) inter-set static stretching (ISS); and (b) no stretching between sets (WSS). The ISS protocol involved passive hip flexion with the knee extended on the dominant lower limb, consisting of four 45-second sets at maximum perceived discomfort level, performed between exercise sets. In the WSS protocol, participants rested passively between sets without stretching. Results: A main effect for condition was found in the number of repetitions (p = .006), indicating that the ISS protocol led to fewer repetitions compared to the WSS protocol. A main effect for sets was also observed ($p \leq$ .0001), showing a progressive decrease in repetitions across sets in both protocols. Regarding TTV, the WSS protocol resulted in higher values than the ISS protocol (p = .01), although the effect size was moderate and non-statistically significant (d = .55; CI95% = -0.15 to 1.22). Both protocols promoted a significant acute increase in ROM, with a greater improvement observed in the ISS protocol (p < .05). Conclusion: These results suggest that while ISS may slightly reduce performance measures such as volume and repetition count, it can be effective strategy for enhance range of motion in trained individuals.
Keywords: Performance analysis, Resistance training, Neuromuscular response, Flexibility, Training volume, Lower limb exercise.

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INTRODUCTION

In the scientific literature, the most commonly used stretching methods are the following: static stretching (SS), ballistic stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF), with SS being the most used when the objective is to increase flexibility. (Medeiros et al., 2016). However, when SS is performed before the start of a resistance training session, it can generate deleterious effects on muscle strength performance. (Behm et al., 2016; Simic et al., 2013; Thomas et al., 2023). Conversely, stretching exercises performed between sets may not interfere with muscle strength performance (Marin et al., 2019; Souza et al., 2020), although other investigations discuss possible negative effects in this condition (JBB et al., 2022; Padilha et al., 2019).

For example, Camargo et al. (JBB et al., 2022) observed that performing inter-set SS on the pectoral muscle, lasting 45 seconds, without any additional rest period after stretching, between sets (7 sets) of the cable fly exercise, provided a 29.9% decrease in the total training volume, when compared to the group without stretching. Nevertheless, Padilha et al. (Padilha et al., 2019) observed a 15.4% decrease in the total volume in the isokinetic knee extension exercise (7 sets), when an inter-set SS was implemented in the quadriceps muscles, lasting 25 seconds, preceded by 15 seconds of passive rest (transition between machines). Therefore, in addition to the duration of the stretching and the muscle group stretched, passive rest after inter-set SS may be a relevant factor in the possible decrease in muscle performance induced by the training method.

In contrast, the findings of Marin et al. (Marin et al., 2019) did not show significant differences in the total number of repetitions when applying an inter-set SS protocol lasting 1 minute, without any additional passive rest for the pectoral muscles, during six sets of the bench press exercise with a load of 80% of 8RM, when compared to the exercise with traditional passive rest. It is plausible that the exercise intensity (80% of 8RM) may have reduced the impact of stretching on strength performance (Ribeiro et al., 2014). Additionally, the authors do not describe the intensity at which the stretching was performed. Therefore, the overload imposed by stretching may not have been sufficient to generate deleterious effects on strength (Kataura et al., 2017; Nakamura et al., 2021), allowing performance in subsequent repetitions to remain unchanged.

Currently, inter-set SS has been widely used as a strategy to increase muscle hypertrophy through its potential effects on intracellular anabolic signalling pathways, stimulated by active and passive force sensors. (Schoenfeld et al., 2022; Van Every et al., 2022). However, none of the aforementioned studies investigated the acute effect of inter-set SS on the range of motion, especially of the hamstring muscles. For the hamstring muscles, improvements in flexibility and strength are considered key modifiable risk factors involved in the occurrence of injuries. (Wan et al., 2021). In contrast, prescribing stretching and strength exercises in the same training session may lead to adaptive mismatches in terms of flexibility and strength. (Behm & Chaouachi, 2011; Bryant et al., 2023; Chaabene et al., 2019; Kay & Blazevich, 2012). Therefore, it is essential to develop new training strategies that aim to improve both the flexibility and strength of the hamstring muscles (Cai et al., 2023).

Thus, the present study aimed to investigate the acute effects of inter-set static stretching of the agonist muscles on total training volume (TTV) during the unilateral leg curl exercise, as well as on the range of motion of the hamstring muscles in trained men. We hypothesized that the experimental protocol consisting of inter-set SS exercises of agonist muscles would increase the range of motion (Covert et al., 2010; Medeiros et al., 2016) and promote small deleterious effects on the total training volume, when compared to the traditional RT protocol.

MATERIALS AND METHODS

Study design

The study was conducted using a randomized crossover design, evaluating the effects of inter-set static stretching of the hamstring muscles during the execution of the unilateral leg curl exercise in strength-trained men. For this, 17 participants attended the laboratory for four sessions, with a 72-hour interval between visits. At the first visit, participants completed the Physical Activity Readiness Questionnaire (PAR-Q) (Adams, 1999), underwent an anthropometric assessment, performed the 10RM load test, and were familiarized with the experimental procedures. At the second visit, participants performed the 10RM retest. During the third and fourth visits, participants were randomly assigned (https://www.randomizer.org) to the conditions: (a) a protocol with inter-set static stretching (ISS); and (b) a protocol without static stretching between sets (WSS). Outcome assessors and data analysts were blinded to the intervention conditions. The ISS protocol was performed through passive hip flexion with the knee extended on the dominant lower limb, consisting of four 45-second sets at the maximum perceived discomfort intensity, performed between the exercise sets. This protocol was defined based on previous studies (Austin, 1999; Padilha et al., 2019), due to its positive effects on the range of motion and lower deleterious effects on strength performance. All sessions were performed in the morning (between 8 am and 12 pm), in a controlled environment with temperatures between 20º and 22ºC.

Participants

The sample consisted of 17 male individuals aged between 24 and 40 years (age = 26.8 ± 5.6 years; body mass = 84.2 ± 10.0 kg; height = 1.76 ± 0.1 m; body fat = 15.5 ± 6.0 %) and selected by convenience. Given that the sample selection was based on convenience, the statistical power of the results [β] was assessed. The following inclusion criteria were adopted: a) having at least two years of experience in strength training; b) not having physical limitations, health problems that could interfere with strength exercise performance, or injuries during all procedures; c) not using medications, drugs, or supplements that could alter their physical performance during the research period. Participants were excluded if: a) They presented any type of disease; b) they had a history of musculoskeletal injuries at least 12 months prior to the study that compromised the performance of the experimental protocols; c) Resting blood pressure ≥ 140/90 mmHg. In addition, individuals were instructed to: a) avoid consumption of alcoholic or caffeine-based beverages for at least 24 hours before the procedures; b) refrain from physical activities involving effort of the lower limbs up to 48 hours before data collection. Informed consent was obtained from all participants, and the study was approved by the local University Ethics Committee (protocol number 7.474.096), in accordance with the Declaration of Helsinki.

Furthermore, this research was conducted in full compliance with the ethical standards of the Journal of Sports Medicine and Physical Fitness, in accordance with the ethical policies of Committee on Publication Ethics (COPE) and International Committee of Medical Journal Editors (ICMJE).

Table 1. Characteristics of individuals.

Variables	Mean	SD
Age (years)	26.8	5.6
Height (cm)	176	0.05
Body mass (kg)	84.2	10.0
Body fat (%)	15.5	6.0
BMI	27.0	2.6

Note. BMC = body mass index; SD = standard deviation.

Anthropometric assessment

The participants' body mass and height were measured using a scale and a stadiometer (Filizola model 31, São Paulo, Brazil). Next, abdominal, pectoral, and medial thigh skinfolds were measured with a skinfold calliper (Sanny, São Bernardo do Campo, Brazil). Subsequently, body composition was estimated by calculating body density. (Jackson & Pollock, 1978) and fat percentage (Siri, 1993), respectively.

10RM test

Before the test, participants performed a specific warm-up consisting of a series of 15 repetitions with approximately 50% of the estimated load for the 10RM, followed by a brief 2-minute rest period. Then, each participant performed the first attempt with the estimated load for the 10RM. The maximum number of attempts was three to five, with rest intervals of 2 to 5 minutes between attempts. In each attempt, there was a progressive increase of between 2.5% and 10% of the load used. If the individual did not reach less than 10RM, the load was reduced by a similar proportion. After a 72-hour interval, a new 10RM test session was performed in order to ensure the reproducibility of the load (retest). To minimize the margin of error in the tests, the following strategies were used: a) all individuals received standardized instructions regarding the tests; b) an experienced evaluator was attentive to the execution technique of the proposed exercise; c) verbal stimuli were used to maintain a high motivational level. The reliability of the 1RM measurements across two trials was high for the single leg curl (ICC = 0.98; 95% CI = 0.96–0.99) exercise.

Resistance exercise protocol

The resistance exercise protocol consisted of the unilateral leg curl exercise, performed for four sets to concentric muscular failure, using a 10RM load and 90-second rest intervals between sets. The training protocol was designed to reflect the number of sets commonly recommended in the literature for muscle hypertrophy-oriented programs and routinely adopted in fitness settings (Santos et al., 2022).

Experimental conditions

Two conditions were used in the study: (a) a protocol with inter-set static stretching (ISS); and (b) a protocol without static stretching between sets (WSS). The ISS protocol consisted of four sets of 45 seconds at maximum perceived discomfort intensity. This protocol was applied at the beginning of the interval between sets, targeting the hamstring muscles of the dominant limb. To do this, the subject was positioned as follows: in a supine position ("*lying on their back on the floor*"), with their knees fully extended and ankles in dorsiflexion. Then, the limb being evaluated was flexed to approximately 90 degrees. Subsequently, the evaluator passively flexed the hip, raising the participants dominant foot to the threshold of discomfort associated with the hamstring muscles, remaining in this position for 45 seconds. (Fakhro et al., 2020). According to Fakhro et al. (Fakhro et al., 2020), this stretching protocol provides stretching of the hamstring muscles to their maximum length. In addition, the stretching time was selected to generate acute increases in the range of motion of the hamstring muscles and avoid a possible decline in strength performance.(Bandy et al., 1997; Palmer et al., 2019). On the other hand, the WSS protocol involved only passive rest between sets.

Range of motion assessment

To measure range of motion (ROM), the protocol adapted from Schuback et al. (Schuback et al., 2004) was used, where the flexibility of the hamstring muscles is measured through the maximum amplitude achieved in knee extension. The range of motion was measured with the aid of a digital goniometer (Shahe Factory Direct, China), which was positioned as follows: fixed arm following the alignment of the greater trochanter of the femur to the lateral epicondyle of the femur and mobile arm following the line of the lateral malleolus to the lateral epicondyle of the femur (Chagas et al., 2008); the evaluated limb was stabilized at approximately

90 degrees with the aid of a box, measuring: 40 cm high by 35 cm wide; the range of motion was measured at the moments: before and immediately after the end of the resistance exercise protocol. This assessment was always performed by the same evaluator.

Assessment of total training volume

The total training volume was expressed by the product of the number of sets, total number of repetitions achieved, and high load, to obtain a measure that represents the total work performed during a session (Tran & Docherty, 2006; Tran et al., 2006).

Statistical analysis

Initially, the normality was assessed using the Shapiro–Wilk test. A two-way repeated-measures ANOVA was conducted for range of motion (ROM), with condition (ISS and WSS) as the first factor and time point (PRE and POST) as the second factor. All participants were included in the statistical analysis.

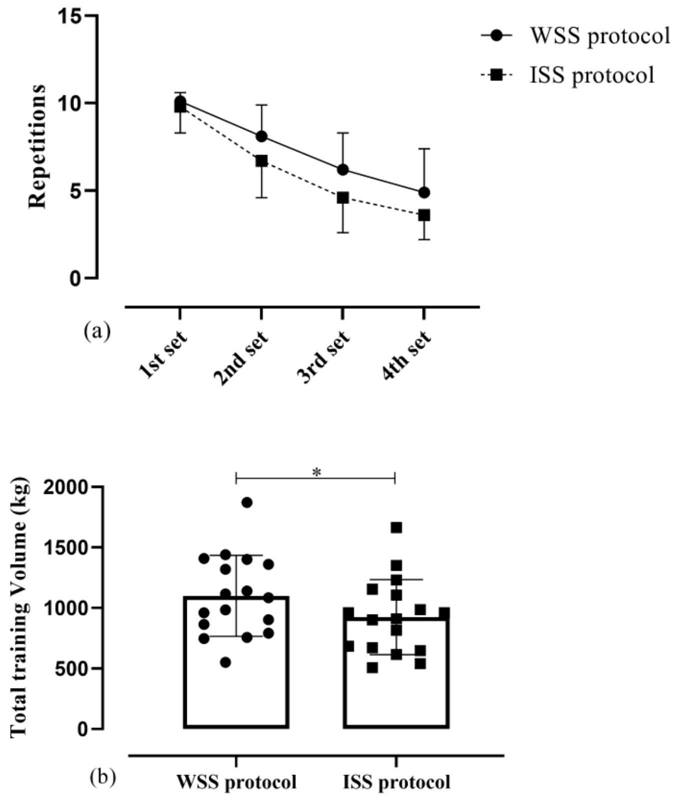
Regarding the number of repetitions, the data were analysed using a repeated-measures analysis of variance (ANOVA), with condition (ISS and WSS) as the first factor and set (1st, 2nd, 3rd, and 4th set) as the second factor. In the case of a significant F-value, post hoc analyses were performed using the Bonferroni correction for multiple comparisons. Moreover, when the assumption of sphericity was violated in analyses related to the number of repetitions, the Greenhouse–Geisser correction was applied. Additionally, the paired t-test was used to compare the total training volume (TTV) between conditions. Statistical significance was set at α = .05 ($p \leq .05$). All statistical analyses were performed using a specialized software program (IBM SPSS, version 25.0, Chicago, IL, USA). Partial eta squared (ηp^2) was used as a measure of effect size for the repeated-measures ANOVA and interpreted as follows: small ($\eta p^2 \geq 0.01$), medium ($\eta p^2 \geq 0.06$), and large ($\eta p^2 \geq 0.14$) (Cohen, 2013). Additionally, to evaluate the magnitude of differences in pairwise comparisons, Cohen's d effect sizes (*d*) with 95% confidence limits [90% CI] were calculated. Effect sizes values were interpreted as follows: trivial (<.19), small (.20 – .49), moderate (.50 – .79), and large (>.80) (Cohen, 2013).

RESULTS

Regarding the number of repetitions, a main effect for condition was found ($F_{(1, 16)}$ = 10.149; p = .006; β = 1.00; ηp^2 = 0.388; large), indicating that the ISS protocol resulted in a lower number of repetitions compared to the WSS protocol (mean difference = 1.2 ± 0.4 reps). Additionally, a main effect for sets was observed ($F_{(2.241, 35.854)}$ = 88.126; $p \leq .0001$; β = 1.00; ηp^2 = 0.846; large), revealing a progressive reduction in repetitions across sets (see Figure 1a). On the other hand, no significant interaction was found between condition and set ($F_{(3, 48)}$ = 2.160; p = .11; β = 0.46; ηp^2 = 0.119; large).

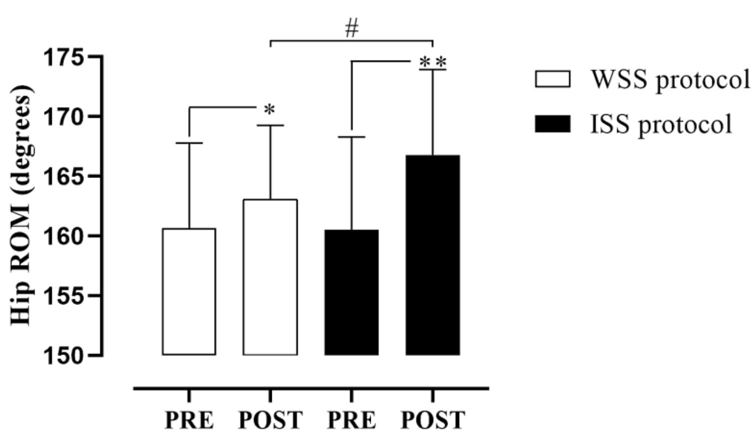
With respect to total training volume, the WSS protocol showed higher values compared to the ISS protocol (WSS = 1,099.8 ± 333.7 kg vs. ISS = 923.8 ± 310.5 kg; Figure 1b), but with a moderate and non-significant effect size (*d* = .55; CI95% = - 0.15 to 1.22; moderate).

Regarding ROM, a main effect for condition was observed ($F_{(1, 16)}$ = 7.815; p = .01; β = 1.00; ηp^2 = 0.328; large), indicating that the ISS protocol resulted in higher ROM values compared to the WSS protocol (mean difference = 1.8 ± 0.6 degrees). A main effect for time point was also found ($F_{(1, 16)}$ = 49.378; $p \leq .0001$; β = 1.00; ηp^2 = 0.755; large), showing that ROM increased in the post-set measurement compared to the pre-set (mean difference = 4.3 ± 0.6 degrees). In turn, a significant interaction between condition and time point was detected ($F_{(1, 16)}$ = 25.743; $p \leq .0001$; β = 0.89; ηp² = 0.617; large), indicating specific differences (see Figure 2).



*Legend. *WSS > ISS (p = .01).*

Figure 1. Number of Repetitions per Set (a) and Total Training Volume (b) in WSS and ISS Protocols.



*Legend. *Post > Pre in the WSS protocol (p = .001); *Post > Pre in the ISS protocol (p ≤ .0001); # ISS > WSS at post-set (p = .001).*

Figure 2. Changes in Range of Motion (ROM) Pre- and Post-Set in WSS and ISS Protocols.

Figure 2 shows that there was no difference between conditions at the pre-set time point (p = .84). On the other hand, both conditions exhibited an increase in ROM after the sets, with greater increases observed in the ISS protocol ($p \leq .0001$; mean difference = 6.2 ± 0.8 degrees; d = .84; CI95% = 0.12 to 1.52; large) compared to the WSS protocol (p = .001; mean difference = 2.4 ± 0.6 degrees; d = .38; CI95% = - 0.31 to 1.04; small). Finally, post-set ROM values were significantly higher in the ISS protocol compared to the WSS protocol (p = .001; mean difference = 3.7 ± 0.8 degrees; d = .55; CI95% = - 0.15 to 1.22; moderate).

DISCUSSION

The aim of this study was to evaluate the acute effects of an inter-set static stretching (ISS) protocol on muscle performance in the unilateral leg curl exercise and on the range of motion (ROM) of the hamstring muscles. Our main findings were: (a) total training volume was higher in the WSS protocol compared to the ISS protocol, but with a non-significant effect size; (b) both protocols promoted a significant acute increase in ROM, with a greater increase observed in the ISS protocol; and (c) both protocols showed a similar progressive decrease in the number of repetitions across sets; however, the ISS protocol resulted in a lower mean total number of repetitions. Therefore, our initial hypotheses were confirmed, indicating a potentially favourable cost-benefit ratio of the inter-set static stretching technique, as it significantly increased ROM at the expense of only a minor performance decrement.

In this context, although the literature shows deleterious effects on muscle strength when static stretching is performed concomitantly with resistance training (Behm et al., 2016; Chaabene et al., 2019; Gomes et al., 2011; Simic et al., 2013; Thomas et al., 2023), the ISS technique has gained prominence as a strategy to increase ROM (Junior et al., 2017; Nakamura et al., 2021) and favour long-term muscular adaptations (Nakamura et al., 2021; Schoenfeld et al., 2022; Van Every et al., 2022). However, one of the main factors that may limit its practical application is the possible drop in performance during the performance of the target exercise of the session (JBB et al., 2022; Padilha et al., 2019). However, based on our findings, it should be considered that inserting a 45-second passive rest period between the execution of the ISS and the subsequent exercise may contribute to reducing the deleterious effects of the technique on strength performance.

In this regard, some evidence suggests that introducing an additional passive rest time can reduce the acute negative effects of stretching in a similar way to that observed in our study. In this sense, according to Souza et al. (Souza et al., 2020), performing an ISS protocol in the anterior chain of the trunk (i.e. pectoralis and anterior deltoid) lasting 30 seconds and 90 seconds of additional passive rest before performing the Bench Press exercise resulted in a decrease of only 8.2% in the total number of repetitions (mean = -1.5 reps) compared to the traditional passive rest protocol. Furthermore, Ribeiro et al. (Ribeiro et al., 2014) had already observed that performing a static stretching protocol of the muscles involved in the execution of the Bench Press exercise (i.e. pectoral, and triceps), lasting 30 seconds and with an additional passive rest of 2 minutes, before performing 4 sets of the target exercise, did not result in negative effects on strength performance.

In contrast, the findings of Camargo et al. (JBB et al., 2022) point to a greater negative effect on total training volume (29.9%), observed through the reduction in the total number of repetitions (mean = 10.9 reps) of the seated cable fly exercise, when this is performed immediately after the execution of the ISS of the anterior chain of the trunk. Corroborating this, Padilha et al.(Padilha et al., 2019) demonstrated that a quadriceps ISS protocol, lasting 25 seconds preceded by a passive rest of 15 seconds (movement to the apparatus) promoted a 23.77% decrease in the total work (joules) of the isokinetic leg extension exercise, associated with a significant reduction in muscle activation seen by EMG.

Therefore, when comparing the results of previous literature with the results obtained in our study, it is observed that the proportion between the stretching time and the rest period before performing the target exercise constitutes a relevant factor to enhance the effectiveness of the ISS method, favouring gains in range of motion and attenuating its negative effects on muscle performance. Regarding the factors responsible for the reduction in neuromuscular capacity associated with the ISS method, the literature mainly highlights mechanisms of a mechanical and neural nature, such as decreased transfer of muscle elastic energy, through decreased stiffness of the muscle-tendon unit, reduced muscle activation, loss of strength due to central neuromuscular inhibition, and decreased local blood flow due to compression of blood vessels (Otsuki et al., 2011; Schoenfeld et al., 2016; Trajano et al., 2013; Wilson et al., 1994). Therefore, adjusting the stretching time so that it is possible to perform an additional period of passive rest between sets of the target exercise appears to be an efficient strategy to dissipate, at least partially, these physiological effects that induce neuromuscular fatigue, without increasing the total session time.

Furthermore, regarding the ROM variable, our results demonstrate that resistance training itself is capable of promoting acute increases in hamstring muscle flexibility, as previously seen (Alizadeh et al., 2023; Favro et al., 2025). However, the ISS regimen promoted significant additional increases (mean difference = 3.7 ± 0.8º), through the performance of only 4 stretching series lasting 45 seconds. In addition to duration, stretching intensity plays a crucial role in ROM. In this sense, evidence shows that greater stretching intensities, especially those approaching pain thresholds, tend to promote greater improvements in flexibility. (Bryant et al., 2023; Kataura et al., 2017; Muanjai, Jones, Mickevicius, Satkunskiene, Snieckus, Rutkauskaite, et al., 2017; Muanjai, Jones, Mickevicius, Satkunskiene, Snieckus, Skurvydas, et al., 2017). Although some evidence suggests that higher stretching intensities impair strength development (Kataura et al., 2017), our findings did not observe major negative effects when stretching the hamstring muscles to the maximum point of pain tolerance.

Regarding the clinical relevance of increasing the ROM of knee extension, previous studies indicate that shortening of the hamstring muscles and greater passive stiffness of the biceps femoris muscle are associated with a higher incidence of injuries and are correlated with compensatory movements and pain in the lumbar spine (Danielsson et al., 2020; Kato et al., 2022; Rudisill et al., 2023; Sadler et al., 2017; Timmins et al., 2016; Yagiz et al., 2024). Thus, the ISS technique performed in this study represents a highly efficient alternative for increasing ROM, preventing the aforementioned factors, without major negative effects on strength development.

However, it is important to consider some methodological limitations of the present study, including: (a) the analysis of a resistance training session consisting of only one exercise; (b) the absence of comparisons between different durations of additional passive rest; (c) inclusion of only male participants; (d) the limited sample size; and (e) the absence of analysis of physiological markers of fatigue. Therefore, future studies are strongly encouraged to more comprehensively investigate the effects of the ISS method on neuromuscular performance.

CONCLUSION

The findings of this study indicate that inter-set static stretching leads to a reduction in the number of repetitions and total training volume compared to a traditional protocol without stretching. However, inter-set static stretching proved to be more effective in acutely increasing hamstring flexibility. Based on our results, we recommend the use of the ISS method in individuals who wish to improve the range of motion of their hamstring muscles and who do not have time available to perform stretching separately from resistance training. However, it is essential to include an additional period of passive rest between stretching and subsequent exercise. This strategy can reduce the deleterious effects of static stretching on neuromuscular performance, especially in exercises performed to concentric muscular failure. By preserving, even partially, the force production capacity, this strategy can make ISS more feasible in practical contexts, balancing the benefits of increasing range of motion with maintaining performance during resistance training.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. I. M. and M. F. conceived and designed the study, coordinated data collection, and wrote the main manuscript text. D. V. G., W. M., F. H. F., and H. M. contributed to data interpretation, manuscript revision, and methodological validation, and assisted with formatting. E. L. and B. R. R. O. supervised the study design, analysed the results, provided critical feedback, and revised the final version of the manuscript. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

DATA AVAILABILITY STATEMENTS

The data supporting the findings of this study, including the datasets used for statistical analyses, have been made available as supplementary material and were uploaded during the manuscript submission process. These datasets contain anonymized information derived from the experimental sessions and are accessible to reviewers through the supplementary files accompanying this article. No additional restrictions apply to data sharing, as all participants provided informed consent for the use of their anonymized data for research purposes.

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