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Original Article

Acute effects of different antagonist muscle stretching methods on agonist muscle strength performance in trained men

Short title: Effects of stretching on strength performance

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ABSTRACT

In the scientific literature, the most commonly used stretching methods are: static (SS), dynamic (DS), and proprioceptive neuromuscular facilitation (PNF). Some studies show that stretching can have deleterious effects on strength performance. However, some evidence suggests that stretching, when applied to antagonist muscles, can positively influence strength performance. Therefore, the aim of this study was to investigate the acute effects of different stretching methods for antagonist muscles on the total training volume (TTV) in a strength training (ST) session in trained men. The sample consisted of 22 trained men. Entry into the experimental protocols was random, through a draw, and performed on four different days: 1) PNF stretching protocol for antagonists followed by an ST session (GPNF); 2) SS protocol for antagonists followed by an ST session (GSS); 3) DS protocol for antagonists followed by an ST session (GDS); 4) protocol without stretching followed by an ST session (GCON). As a result, no significant differences were observed in TTV when comparing the different experimental protocols. In conclusion, stretching exercises, when applied acutely to antagonist muscles, regardless of the method, do not promote deleterious effects on the TTV of agonist muscles.

Keywords: Muscle Stretching Exercises; Muscle Strength; Resistance Training; Hamstring Muscles.

INTRODUCTION

Flexibility is defined as the ability to bring a given joint to its maximum range of motion (ACSM, 2018). Some physical capacities such as strength, muscle power, and flexibility play a very important role in maintaining or increasing functional capacity and improving physical performance (Leite et al., 2015; Andrade et al., 2018). Therefore, stretching exercises have been commonly used with the aim of preventing injuries, increasing functional capacity, and improving physical performance (Alves et al., 2021; Behm et al., 2021).

In the scientific literature, the most commonly used stretching methods are: static (SS), ballistic (BS), dynamic (DS), and proprioceptive neuromuscular facilitation (PNF) (Behm et al., 2021; Miranda et al., 2022), with the PNF method being the most used when the goal is to increase flexibility (Nascimento et al., 2020; Miranda et al., 2022; Silva et al., 2023). In a given joint, antagonist and agonist muscles are recruited simultaneously, in a synchronised and coordinated manner, with the aim of improving the precision and efficiency of a given movement (Busse et al., 2006; Higginson et al., 2006). Thus, it has been suggested that stretching antagonist muscles, through mechanisms of reciprocal inhibition, stress relaxation, and reduction of muscle-tendon unit stiffness, may induce an increase in the strength performance of agonist muscle (Miranda et al., 2022; Longo *et al*., 2025).

Indeed, some studies show that acute stretching can have deleterious effects on repetition performance, total training volume (TTV), and load performance (Marchetti et al., 2015; Barbosa et al., 2018; Moreira et al., 2022; Longo et al., 2025). However, some evidence suggests that stretching exercises may not interfere with strength performance (De Freitas et al., 2020; Gomes et al., 2021; Pessoa et al., 2023). Nevertheless, some contemporary studies determine that stretching, when applied acutely to antagonist muscles, can positively influence repetition performance, TTV and load performance (Gomes et al., 2014; Miranda et al., 2022).

In a study conducted by Miranda et al. (2014), it was observed that an SS protocol consisting of two 40-second sets applied to antagonist muscles promoted improvements in load performance in the 10 RM test for the leg curl and scott curl exercises in strength-trained men and women. However, a study by Nascimento et al. (2019) showed that a PNF stretching session consisting of a 30-second set applied to antagonist muscles did not influence repetition performance in the leg extension exercise in strength-trained men.

Additionally, De Freitas et al. (2020) determined that a PNF stretching session consisting of three 30-second sets applied to antagonist muscles did not interfere with repetition performance in the CE exercise in strength-trained men. Furthermore, Pessoa et al. (2023) elucidated that an SS protocol consisting of two 20-second sets, applied to antagonist muscles, did not interfere with TTV in the leg extension exercise in trained men. However, Montalvo et al. (2025) determined that a DS protocol, applied chronically to antagonist muscles, promoted improvements in vertical jump performance and isokinetic strength in trained and sedentary men.

Therefore, it seems that the use of different stretching volumes, intensity, training level, sex, stretching methods and measured variables related to strength performance can influence, in a distinct way, the effects of stretching antagonist muscles on the strength performance of agonists, with the TTV an important variable that is not very well elucidated in the scientific literature. In parallel, recent bibliometric evidence has demonstrated a sustained growth in scientific production addressing strength training variables and performance-related outcomes in different sports contexts, highlighting increasing methodological refinement and interest in neuromuscular performance mechanisms (Venâncio et al., 2025). Thus, the objective of the present study was to investigate the acute effects of different stretching methods of antagonist muscles on the TTV in the leg extension exercise in trained men.

METHODS

Participants

The sample consisted of 22 trained men (27.85 ± 7.79 years old; 72.38 ± 18.56 kg body mass; 167.00 ± 10.90 cm height) and were selected by convenience. The sample size was calculated using the G*Power software (G*Power 3.1.9.7, Heinrich Heine-Universität, Düsseldorf, Germany). Assuming the values of effect size = 0.56; α-error = 0.05; Power = 0.8, the total sample size was 22 participants. The inclusion criteria were: a) being between 18 and 45 years old; b) having at least six months of strength training (ST) practice, with a minimum frequency of three sessions per week, and having prior experience in the leg extension exercise; c) a negative Physical Fitness Readiness Questionnaire (PAR-Q). Similarly, the following exclusion criteria were established: a) having musculoskeletal injuries that compromise the performance of the experimental protocols; b) using ergogenic aids or medications for performance or health purposes; c) having any disease.

All subjects signed a free and informed consent form before participating in the study, which was conducted in accordance with the ethical standards set forth in Law No. 14,874, of May 28, 2024 (BRAZIL, 2024). This study was approved by the Research Ethics Committee with Human Beings of the Clementino Fraga Filho University Hospital, Federal University of Rio de Janeiro, CAEE No. 27779119.2.0000.5257, with the approved registration number 3,904,690.

Procedures

Six visits were conducted with 48-hour intervals between them. During the first two visits, the following procedures were performed: a) completion of the informed consent form and the PAR-Q; b) anthropometric measurements; c) familiarisation with the experimental

protocols; d) 10-RM test (first visit); e) 10-RM retest (second visit). During the remaining visits, the experimental protocols were performed.

Furthermore, all individuals were instructed to maintain their respective routines of eating, hydration, and physical exercise, and to avoid alcohol consumption at least 24 hours prior to testing and training sessions.

This study had a randomised, crossover design with simple randomisation. Entry into the experimental protocols was random, through a lottery, and performed on four different days: 1) PNF stretching protocol of antagonists (hamstrings) followed by resistance training (GPNF); 2) SS protocol of antagonists (hamstrings) followed by resistance training (GSS); 3) DS protocol of antagonists (hamstrings) followed by resistance training (GDS); 4) protocol without stretching and resistance training (GCON).

Furthermore, in all experimental conditions, the resistance training session consisted of the following exercise: leg extension; three sets, performed to concentric failure; loads of 100% of 10RM; and 90-second intervals between sets. Additionally, in order to increase the ecological validity of this study, the cadence was not controlled.

Additionally, in all experimental protocols, the total number of repetitions performed at the end of each of the three series was recorded, and the TTV was subsequently calculated. Furthermore, in all experimental protocols, except for GCON, the ST session was performed immediately after the end of the intervention protocol. Furthermore, it should be noted that not controlling for cadence is a limitation of the present study; therefore, future studies that control for cadence are suggested.

Additionally, all experimental protocols were performed at the same time of day (12:00 to 17:00 hour) in order to reduce the effects of circadian variation (Pazetti-Baccili et al., 2024); the ambient temperature was controlled, using a thermometer, so that all experimental conditions were performed under the same temperature conditions (between 20° and 25°C);

and height and body mass were measured using a scale (Welmy, W200a) and a stadiometer (Welmy, W200a).

In the PNF stretching protocol, the subject was initially positioned as follows: lying in a supine position, hips and knees extended, and ankles in dorsiflexion. Then, with the heel resting on the evaluator's shoulder, the subject passively performed hip flexion with the knee fully extended, to the greatest possible range of motion (ROM), at an intensity between levels 61 and 80 (maximum intensity) of the PERFLEX scale (0 – 110) (Dantas et al., 2008). Upon reaching ROM, the subject, with resistance applied by the evaluator, performed a maximum voluntary isometric action (MVIA) of the hip extensor muscles for six seconds. Subsequently, the subject, with their heel resting on the evaluator's shoulder, performed a passive hip flexion with the knee fully extended, at the maximum possible ROM, at an intensity between levels 61 and 80 (maximum intensity) of the PERFLEX scale (0 – 110), and upon reaching that ROM, maintained it for 30 seconds (Gama et al., 2007; Dantas et al., 2008). Additionally, it is important to emphasise that a single series of 30 seconds was performed for each lower limb, without any interval between limbs (Gama et al., 2007).

In the static stretching protocol, the subject was initially positioned as follows: lying in a supine position, hips and knees extended, and ankles in dorsiflexion. Then, with the heel resting on the evaluator's shoulder, the subject performed a passive hip flexion, with the knee fully extended, to the greatest possible ROM, at an intensity between levels 61 and 80 (maximum intensity) of the PERFLEX scale (0 – 110), and upon reaching this ROM, it was maintained for 30 seconds. (Gama et al., 2007; Dantas et al., 2008). Additionally, a single series lasting 30 seconds was performed for each lower limb, without any interval between limbs (Gama et al., 2007).

In the dynamic stretching protocol, the subject was initially positioned as follows: lying in a supine position, hips and knees extended, and ankles in dorsiflexion. Then, the subject actively performed a hip flexion with the knee fully extended, at the maximum possible ROM, at an intensity between levels 61 and 80 (maximum intensity) of the PERFLEX scale (0 -110) (Dantas et al., 2008). Upon reaching this ROM, the subject actively performed hip extension with the knee fully extended, returning to the initial position. These motor movements were repeated for 30 seconds (Gama et al., 2007; Pereira et al., 2022). Furthermore, a single series lasting 30 seconds was performed for each lower limb, without any interval between limbs (Gama et al., 2007; Gonçalves et al., 2013).

Regarding the 10-RM test, initially, a warm-up session was performed consisting of one set of 20 repetitions with a load of 50% of the 10RM usually used by each individual (Miranda et al., 2022). Then, after a five-minute interval, up to five attempts were performed with five-minute intervals between them, and if the load was not found by the fifth attempt, a new test was performed 48 hours later. The test was interrupted under the following conditions: a) when more than ten repetitions were performed; b) when a given individual reached concentric failure on the tenth repetition. Furthermore, in order to guarantee the reproducibility of the load, a new test session was performed 48 hours later, considering the highest load found on the two days of testing (Valério et al., 2022); and the same evaluator supervised all testing sessions.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 22.0; SPSS, Inc., Chicago, IL, USA). Initially, to test the normality of the data, the Shapiro-Wilk normality test and analysis of skewness and kurtosis were performed (Chan, 2003). With the normality of the data not rejected, a one-way ANOVA followed by a Bonferroni post-hoc test was performed

to determine if there were significant differences between the experimental groups in relation to TTV. For all inferential analyses, a p-value < 0.05 was adopted.

RESULTS

Table 1 presents the mean and standard deviation values of TTV in each of the experimental conditions. As a result, no significant differences were observed in TTV when comparing the different experimental protocols (p = 0,320; df = 3).

Table 1. Mean and standard deviation (SD) values of TTV in each of the experimental conditions.

Experimental protocols	TTV (kg)
GPNF	3513.00 + 707.10
GSS	4011.00 + 1675.46
GDS	3366.00 + 720.74
GCON	2658.00 + 1055.63

TTV: total training volume; kg: kilogram; GPNF: PNF antagonist protocol; GSS: SS antagonist protocol; GDS: DS antagonist protocol; GCON: protocol without stretching; PNF: proprioceptive neuromuscular facilitation; SS: static stretching; DS: dynamic stretching; kg: kilogram; p <0,05.

DISCUSSION

The main finding of the present study was that stretching exercises, when volume and intensity are equalised and when applied to antagonist muscles, regardless of the method, in an acute manner, do not promote deleterious effects on the TTV of agonist muscles in strength-trained men. Therefore, these findings corroborate some previous evidence that elucidated that stretching antagonist muscles does not negatively interfere with the performance of agonist muscles (De Freitas et al., 2020; De Souza et al., 2020; Cé et al., 2020; Valério et al., 2022).

In a similar study, De Freitas et al. (2020) investigated the acute effect of different volumes of PNF stretching of antagonist muscles on the strength performance of agonist muscles in trained men. The PNF stretching protocol consisted of one or two 30-second sets, depending

on the experimental condition, applied to the hamstring muscles of both limbs. Furthermore, the PNF stretching session was performed immediately before the start of the resistance training session, and the intensity of the stretch was not controlled. As a result, the authors observed that PNF stretching, regardless of volume, when applied to antagonist muscles, did not interfere with repetition performance in the controlled exercise in strength-trained men.

Additionally, a study by De Souza et al. (2020) investigated the effects of intra-set SS of antagonist muscles on the strength performance of agonist muscles in strength-trained men. The SS protocol consisted of two 30-second sets, without intervals between them, applied to the hamstring muscles of both limbs. Furthermore, the SS exercises were performed immediately before the start of each set, and the intensity of the stretch was not controlled. It was then determined that intra-set SS of antagonist muscles did not influence the total volume of repetitions in the leg extension exercise.

Furthermore, a study conducted by Cé et al. (2021) investigated the acute effects of SS of antagonist muscles on the strength performance of agonist muscles in sedentary men. The SS session consisted of five sets of 45 seconds, with 15-second intervals between them, applied to the plantar flexor muscles of the dominant limb. Moreover, the SS session was applied immediately before the start of the resistance training session. In conclusion, it was found that SS did not interfere with the electromyographic activity and the force production capacity of the agonist muscles.

However, in a subsequent study, Miranda et al. (2022) investigated the acute effects of different volumes of intra-set PNF stretching of antagonist muscles on the strength performance of agonist muscles in physically active men. The PNF stretching session consisted of three sets of 20 or 30 seconds, depending on the experimental condition, without intervals between them, applied to the hamstring muscles of the dominant limb. Furthermore, the stretching session was performed immediately before the start of each set, and the

intensity of the stretch was not controlled. As a result, it was observed that the higher volume PNF stretching protocol (3 sets of 30 seconds) promoted improvements in the total volume of repetitions in the unilateral leg extension exercise.

However, it is important to highlight the different volumes and intensity of stretching, the timing of the stretching exercises, the exercises and the training levels used in the present study and in the study conducted by Miranda et al. (2022), which may possibly support the findings of Miranda et al. (2022).

This conservative effect profile appears consistent with broader trends identified in recent bibliometric analyses, which highlight an increasing emphasis on methodological control, volume manipulation, and specific interpretations of results within strength training research (Venâncio et al., 2025). In the scientific literature, several neuromuscular mechanisms are elucidated as potentially responsible for acute changes in strength performance after a stretching session (Trajano et al., 2017). Among these mechanisms, alterations in afferent feedback from type I, II, III, and IV fibres, changes in the viscoelastic properties of the muscle-tendon unit, and reductions in muscle stiffness (Cé et al., 2021; Warneke et al., 2024) can be considered the most relevant mechanisms. Furthermore, it should be noted that the volume of stretching may be associated with the magnitude of the deleterious effects on strength performance (Behm et al., 2021). Therefore, it is speculated that the reduced volume of stretching used in the present study, in each of the experimental protocols, was not sufficient to promote acute neuromuscular changes in antagonist muscles and, consequently, to promote improvements in the strength performance of agonist muscles.

Furthermore, it is important to highlight that the present study presents some important methodological limitations, such as: a) sample size; b) using a resistance training session composed of a single exercise; c) using only strength-trained individuals; d) using only male individuals. Therefore, it is suggested that future studies be conducted with a larger sample

size, using resistance training sessions composed of multiple exercises, using other populations in their respective samples and using female subjects.

CONCLUSIONS

Stretching exercises, when applied to antagonist muscles and when volume and intensity are equalised, regardless of the method, do not promote deleterious effects in the performance of agonist muscle strength in trained men. Therefore, based on these findings, it is suggested that trainers, resistance training practitioners, and physical conditioning professionals use stretching of antagonist muscles as a warm-up when the intention is to prepare the neuromuscular system for a resistance training session, since stretching antagonist muscles does not promote deleterious effects on the strength performance of agonist muscles. However, it should be noted that, in the present study, only one exercise, one intensity, and one stretching exercise were tested. Furthermore, only trained men were used, and only the acute effects were analysed.

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