



Revista Brasileira de  
**CIÊNCIAS DO ESPORTE**

[www.rbceonline.org.br](http://www.rbceonline.org.br)



ORIGINAL ARTICLE

**Static or dynamic stretching program does not change the acute responses of neuromuscular and functional performance in healthy subjects: a single-blind randomized controlled trial**



**Germannna Medeiros Barbosa\*, Glauko André Figueirêdo Dantas, Bianca Rodrigues Silva, Túlio Oliveira Souza, Wouber Héricksen Brito Vieira**

*Universidade Federal do Rio Grande do Norte, Departamento de Fisioterapia, Laboratório de Análise da Performance Neuromuscular, Natal, RN, Brazil*

Received 3 December 2016; accepted 19 June 2018  
Available online 27 July 2018

**KEYWORDS**

Joint range of motion;  
Evaluation;  
Athletic performance;  
Muscle strength

**PALAVRAS-CHAVE**

Amplitude de movimento articular;  
Avaliação;  
Desempenho esportivo;  
Força muscular

**Abstract** The purpose of this study was to compare the effects of a single hamstring static or dynamic stretching session and a 10-session stretching program on the range of motion, neuromuscular performance and functional performance of healthy subjects. Forty-five, healthy, active men were divided into three groups: control; static stretching and dynamic stretching. There were no significant differences in ratings between the experimental and control groups for any of the variables ( $p > 0.05$ ). It can be concluded that neither a single session of hamstring static or dynamic stretching nor a 10-session stretching program affected range of motion, neuromuscular or functional performance.

© 2018 Colégio Brasileiro de Ciências do Esporte. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

**Programa de alongamento estático ou dinâmico não altera as respostas agudas do desempenho neuromuscular e funcional de sujeitos saudáveis: ensaio controlado randomizado e cego**

**Resumo** A proposta deste estudo foi comparar os efeitos de uma única sessão de alongamento estático ou dinâmico dos isquiotibiais e dez sessões do programa de alongamento na amplitude de movimento e desempenho neuromuscular e funcional de indivíduos saudáveis. Quarenta e cinco homens ativos e saudáveis, foram distribuídos em três grupos: controle, alongamento estático e alongamento dinâmico. Não houve diferença significativa entre os grupos experimentais e controle para todas as variáveis ( $p > 0,05$ ). Pode-se concluir que nem

\* Corresponding author.

E-mail: [germannamb@gmail.com](mailto:germannamb@gmail.com) (G.M. Barbosa).

<https://doi.org/10.1016/j.rbce.2018.06.002>

0101-3289/© 2018 Colégio Brasileiro de Ciências do Esporte. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

**PALABRAS CLAVE**

Rango del movimiento articular;  
Evaluación;  
Rendimiento deportivo;  
Fuerza muscular

uma única sessão de alongamento estático e dinâmico dos isquiotibiais, nem 10 sessões do programa de alongamento afetaram a amplitude de movimento e o desempenho neuromuscular e funcional.

© 2018 Colégio Brasileiro de Ciências do Esporte. Publicado por Elsevier Editora Ltda. Este é um artigo Open Access sob uma licença CC BY-NC-ND (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

### Un programa de estiramientos estáticos o dinámicos no modifica las respuestas agudas del rendimiento neuromuscular y funcional en individuos sanos: ensayo ciego controlado de distribución aleatoria

**Resumen** El propósito de este estudio fue comparar los efectos de una sola sesión de estiramientos estático o dinámico en los isquiotibiales, y diez sesiones del programa de estiramiento en el rango de movimiento y rendimiento neuromuscular y funcional de individuos sanos. Cuarenta y cinco hombres activos y sanos fueron divididos en tres grupos: control, estiramiento estático y estiramiento dinámico. No hubo ninguna diferencia considerable entre los grupos experimentales y de control respecto a todas las variables ( $p > 0,05$ ). Se puede concluir que ni una sola sesión de estiramiento estático o dinámico de los isquiotibiales ni 10 sesiones del programa de estiramiento afectaron al rango de movimiento ni al rendimiento neuromuscular y funcional.

© 2018 Colégio Brasileiro de Ciências do Esporte. Publicado por Elsevier Editora Ltda. Este es un artículo Open Access bajo la licencia CC BY-NC-ND (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

Muscle stretching is one of the main components of exercise and conditioning programs (Magnusson and Renström, 2006; Garber et al., 2011) and its primary response is increased flexibility (Johnson et al., 2014). Although most studies have shown that stretching exercises increase range of motion (ROM), it is known that acute stretching has no impact on the risk of muscle injury (Behm et al., 2016). Moreover, previous systematic reviews have reported temporarily impaired performance, especially when stretching is applied before exercise (Kay and Blazevich, 2012; Behm et al., 2016).

Among the main stretching techniques, static stretching (SS) is widely used by athletes and the physically active population, particularly self-stretching (Bandy et al., 1998). In addition to SS promoting an increase in ROM, recent studies have reported a decline in strength, power or endurance of up to 20.5% after a single SS session (Behm et al., 2016). However, the findings are contradictory, mainly because of differences in stretching intensity and duration (Apostolopoulos et al., 2015; Souza et al., 2015; Behm et al., 2016). Stretching intensity may not have been adequately addressed in previous studies due to its subjective nature (Apostolopoulos et al., 2015). With respect to stretching duration, there seems to be a dose-response relationship whereby total SS duration per muscle group  $\geq 60$  s has a greater likelihood of decreasing immediate performance when compared to durations  $< 60$  s (Behm et al., 2016).

Given the possibility of impaired performance, several research groups, including the American College of Sports

Medicine (Garber et al., 2011) and European College of Sports Sciences (Magnusson and Renström, 2006), have suggested other types of stretching exercises, such as dynamic stretching (DS), during warm-up protocols or competition. This maneuver involves contracting the muscle group antagonist to the target muscle, promoting an increase in muscle temperature, as occurs in the warm-up (Cramer et al., 2005). Studies have reported that DS promotes a similar acute increase in ROM, when compared to SS maneuvers (Curry et al., 2009). However, factors such as velocity, sets and repetitions can alter responses to stretching (Yamaguchi and Ishii, 2014), making it difficult to compare studies. Moreover, the duration of the effects on ROM after a DS program remain unknown.

The beneficial acute effects of DS on isokinetic performance in terms of muscle strength and power have been underscored (Amiri-Khorasani and Kellis, 2013), in addition to enhancing the functional performance in vertical jumps (Yamaguchi and Ishii, 2014) and other sport-specific activities. However, although studies show positive acute effects, there are reports of reduced performance after DS or no benefits whatsoever. For example, Costa et al. (2014) found a decline in hamstring concentric and eccentric strength and, consequently, the hamstring/quadriceps ratio after acute DS. Similarly, Curry et al. (2009) evaluated the effects of SS and DS on vertical jump performance, showing a reduction after 30 min for both stretching routines.

In addition to acute changes, some studies investigated the chronic effects of stretching on performance. Kokkonen et al. (2007) demonstrated an increase in one-repetition

maximum (1-RM), muscular endurance, vertical jump height and the 20-m sprint after a 10-week SS program performed three times a week. [Bazett-Jones et al. \(2008\)](#) found that jump performance or the 55-m sprint time did not change after 6-week hamstring static stretching training. In addition to the contrasting results, it is still unknown whether performance responses after a single SS session change when compared to the effects of a stretching program. Likewise, it is also unknown if regular DS can modify performance when compared to a single session.

As such, the aim of this study was to compare the effects of a single hamstring SS or DS session and a 10-session stretching program on the ROM, neuromuscular performance, and functional performance of healthy subjects. The hypotheses were that: (1) a single session of SS or DS does not change ROM, but SS decreases and DS increases performance; (2) the SS program increases ROM, whereas DS does not; (3) both stretching programs improve performance, when compared to a single session.

## Methods

### Study design

This is a blind, randomized, controlled clinical trial, in which the first researcher was responsible for evaluating and reevaluating the participants, the second for registering, randomizing and instructing the subjects about the intervention protocol, and the third for statistical analyses. The present study was approved by the Research Ethics Committee of the University (number 1.132.671), and all subjects signed a consent form, in accordance with Resolution 466/2012 of the National Health Council (CNS) and Declaration of Helsinki. The study was registered at [ClinicalTrials.gov](http://ClinicalTrials.gov) (NCT02689544) and conducted at the Therapeutic Practice Laboratory of the Physiotherapy Department from July 2015 to January 2016. Before the experiment, each participant read and signed a consent form and was advised of the procedures, discomfort and risks, as well as the benefits of the research and their right to withdraw at any time.

Sample size was calculated using G\* Power software (version 3.1.3; University of Trier, Trier, Germany) and the procedures followed the recommendations of earlier studies ([Beck, 2013](#)). Based on a previously performed pilot study (9 volunteers/3 per group), the sample was calculated using ROM, fatigue indices and vertical jump variables. Prior statistical analysis demonstrated that ROM had the largest sample size among the three variables. Partial  $\eta^2$ , effect size ( $f$ ) and a significance level of  $p=0.05$  was adopted, as well as power ( $1 - \beta$ ) of 0.95, correlation coefficient of 0.5 and effect size of 0.25. A sample of 15 participants was calculated for each group, providing a statistical power of 95.5%.

### Subjects

Healthy, physically active men were invited to take part in the study through written brochures and personal contact at universities and colleges in Natal, Rio Grande do Norte state, Brazil. Inclusion criteria were men aged between 18 and 28 years, body mass index (BMI) between 21 and

25 kg/m<sup>2</sup>; not participating in a lower limb stretching program; being healthy, according to the Physical Activity Readiness Questionnaire – PAR-Q ([Thomas et al., 1992](#)), performing recreational physical activity at least three times a week according to the International Physical Activity Questionnaire – IPAQ ([Craig et al., 2003](#)); no history of lower limb injury, trauma or disease in the previous six years; and limited ROM (degree of muscle shortening) of at least 15° in active knee extension ([Yamaguchi and Ishii, 2014](#)) of the non-dominant limb (180° is considered total knee extension, at 90° hip flexion). Exclusion criteria were not undergoing any assessment and/or intervention procedure; injuries during assessment or the intervention period; and withdrawing from the study.

### Randomization and intervention

After the inclusion criteria were analyzed, the subjects were registered by the second researcher, randomized using <http://www.randomization.com> (Code: 21318) and allocated to one of the three groups:

- Control group (Cg) individuals were not submitted to any intervention, but were informed of the importance of stretching. During the study period, the subjects were instructed not to participate in stretching programs or perform any of the maneuvers.
- Static stretching group (SSg) participants lay on the examination table in the supine position and performed a hip flexion with knee extended and the contralateral limb at 90° of knee flexion. After a rubber band was placed on the plantar surface of the foot, they performed three 30-second sets of hamstring self-stretching exercises for each limb, starting with the non-dominant leg ([Bandy et al., 1997](#)). The maneuvers were carried out until the subjects reported mild discomfort, with a 30-second interval between sets, for approximately three minutes. The self-stretching maneuver was chosen for its easy application, in addition to being traditionally performed by athletes and physically active people.
- Dynamic stretching group (DSg): after familiarizing themselves with the movement, participants assumed a standing position. They contracted the antagonist muscle of the hamstrings (quadriceps) until they felt mild discomfort in the latter. Next, they performed dynamic hip flexion with knee extension according to an established “beep” rate. The protocol was adapted from [Meerits et al. \(2014\)](#), with three sets of 30 repetitions for each limb (starting with the non-dominant limb), for approximately three minutes.

Both legs were submitted to the intervention because not stretching the dominant limb could interfere with the results. The intervention groups (SSg and DSg) underwent a stretching program three times a week, between noon and 3 pm, until completing the 10 sessions.

### Procedures and assessment

The participants from the three groups were assessed four times. The first assessment (Pre-1st) was conducted at least

48 h before the first stretching session, in order to avoid the presence of residual test effects. The following assessments (Post-1st, Post-10th and Post-48 h) occurred immediately after the first stretching session (acute response), after the tenth stretching session (post-stretching program response), and 48 h after the final assessment (delayed response after the tenth stretching session), respectively. Participants from the Cg were also evaluated four times, such that the time between their assessments coincided with the other groups' assessments. The non-dominant limb of all participants was tested for the variables below. In order to identify the non-dominant limb, subjects were asked which leg they used to kick a soccer ball (Amiri-Khorasani and Kellis, 2013). The evaluation was performed in the following order.

### Flexibility

A universal goniometer (Carci<sup>®</sup>; unit: degrees), an examination table and a wooden device (Chan et al., 2001) were used to assess flexibility. An earlier study shows good intrarater reliability (intra-class correlation coefficients – ICC: 0.91–0.99; Barbosa et al., 2017). A standard error of measurement (SEM) of  $\pm 5^\circ$  is clinically acceptable for most dysfunctions (Bruton et al., 2000). The wooden device was built to maintain the hip of the evaluated limb at  $90^\circ$  flexion and the contralateral limb immobilized on the examination table with a Velcro strap (Barbosa et al., 2017). The participants were asked to move their leg toward knee extension three times. Each measurement was blind and the mean values between the three trials were recorded.

### Muscle latency

The uptake of the electromyographic signal (EMG) was performed by an eight-channel conditioner module (CS 800 – EMG System do Brasil Ltda<sup>®</sup> – São José dos Campos/SP, Brazil) with 12-bit resolution and common-mode rejection ratio  $>80$  Db. To capture the electrical activity of the muscle, simple differential active surface electrodes were used, with a signal amplified 2000 times. Signals were captured at a sampling frequency of 2000 Hz and filtered between 20 and 500 Hz (De Luca, 1997). The electrode was placed on the biceps femoris muscle, according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) criteria (Hermens et al., 2000). An electronic goniometer was attached to the knee joint to capture the initial moment of angular variation.

The uptake of muscle latency (ML) was performed with the participant in a ventral decubitus position, on an examination table, and the non-dominant knee flexed at  $90^\circ$ . The non-dominant leg was connected to a device located in front of the examination table via a cord attached to a Velcro strap around the ankle. Each participant was familiarized with the movement performed during signal capture (active knee extension), and instructed to start the movement at the verbal command "ready, set, go!". Subjects then tried to extend their leg as far as possible and, after 3 s, the resistance from the rope attached to the device was quickly released, causing a sudden change in the subject's knee angulation. While the electronic goniometer detected the beginning of joint angle variation, the EMG electrode captured the beginning and amplitude of muscle activation in order to record knee extension deceleration.

To analyze ML, the initial angular variation measured by the electronic goniometer (TE) and initial effective muscle activation (TM) were used. The TE was the instant, in milliseconds (ms), when the electronic goniometer showed an increase in knee extension of at least  $3^\circ$  ( $TE \geq 3^\circ$ ). In order to obtain TM, the amplitude of the BF muscle at rest was obtained using the root mean square (RMS), in  $\mu$ V. The onset of effective muscle activation was the instant, in ms, when the muscle RMS value was around 3 times the standard deviation of the resting value. Muscle latency was calculated as  $TM-TE$  (Esposito et al., 2009; Nogueira et al., 2014).

### Isokinetic performance

Before the beginning of each test, an isokinetic dynamometer (Biodex Multi-Joint System 3, New York, USA) was calibrated (one calibration/subject) according to the manufacturer's specifications and recommendations (Biodex System 3 Pro). The passive peak torque of the hamstring muscle group was captured and normalized by body mass (pPT/BM), starting from  $90^\circ$  of knee flexion until full knee extension ( $180^\circ$ ) at a velocity of  $5^\circ$  (Magnusson et al., 1996) and the limb relaxed. To evaluate the fatigue index, 30 maximum concentric knee flexor and extensor muscle contractions at  $240^\circ/s$  (Cramer et al., 2004) were recorded at a starting position of  $90^\circ$  knee flexion until  $165^\circ$  knee extension. This index is expressed as a percentage based on the difference in muscle work production between the first and last third of the 30 repetitions. Before all testing procedures, gravity correction was performed with the assessed limb relaxed, at  $30^\circ$  knee semi-flexion. Furthermore, all subjects were seated on the isokinetic dynamometer chair and stabilized with straps around the hip and thoracic region, as well as the thigh of the evaluated limb. Individuals were familiarized with the equipment; this consisted of three sub maximum contractions before the fatigue index test, in addition to visual and verbal feedback. The isokinetic dynamometer demonstrated excellent test–retest reliability for pPT (ICC = 0.88–0.97; SEM = 2.24 Nm; Aquino et al., 2007) and for high speed concentric tests (ICC = 0.82–0.95; SEM = 13.2–17.7 Nm; Worrell et al., 1994; Habets et al., 2018).

### Functional performance

The countermovement vertical jump was performed with participants on a *Jump System Pro*<sup>®</sup> contact mat, with hands placed on the iliac crest region of the hip. At the appropriate time, they flexed the knee to gain thrust and then performed a vertical jump, initializing and finishing the movement with both feet on the contact mat (Kenny et al., 2012). An SEM of 0.79 cm was recorded in an earlier study (Attia et al., 2017). Before the three trials, they were allowed one repetition to familiarize themselves with the test. The highest jump was analyzed and an interval of 30 s between repetitions was established.

### Discomfort and affective valence

The discomfort caused by stretching was recorded at the end of each session using the Visual Analog Scale – VAS (McHugh and Nesse, 2008), consisting of a 100-millimeter ruler, with "no discomfort" (0 mm) written at one end and "maximum discomfort" (10 mm) at the other. VAS test–retest reliability

has been shown to be high with ICC scores between 0.70 and 0.83 (Li et al., 2007).

The affective valence was determined at the end of stretching protocols using a Feeling Scale (Frazao et al., 2016), consisting of an 11-point bipolar scale ranging from +5 ('very good') to -5 ('very bad'). This scale has been shown to be a valid measure of the affective state in young people (Hardy and Rejeski, 1989). A previous study showed a strong correlation between the scale (0.89–0.97) and ratings of perceived exertion (Rose and Parfitt, 2008).

## Statistical analysis

The Shapiro–Wilk test was used to confirm normal data distribution and Levene's test for homogeneity of variances. When the sphericity assumption was not confirmed using Mauchly's test, the Greenhouse–Geisser correction was used. A 2-factor analysis of variance (ANOVA) was carried out for all variables, with group (control, static stretching and dynamic stretching) as the between-subject factor and time (baseline, Post-1st, Post-10th and Post-48 h after the final intervention) as the within-subject factor. When group–time interactions were observed, Tukey's post hoc test was used to identify possible differences. The chi-squared test was applied to verify a possible association between group and sensation (pleasantness/comfort and unpleasantness/discomfort) during stretching. The significance level was set at .05 for all analyses and the data expressed as mean ± standard deviation. Cohen's *d* coefficient was used to calculate the effect size of the interaction for all variables. An effect size greater than 0.8 was considered large; between 0.5 and 0.7, moderate; from 0.4 to 0.2, small; and 0.1 or <0, no effect (Cohen, 1988). The statistical procedures were conducted using the

Statistical Package for the Social Sciences (SPSS – 20.0) software.

## Results

Fig. 1 shows the flowchart of participants throughout the trial. Of the 58 volunteers, five did not meet the inclusion criteria. Of these, 53 were randomized and 45 completed the intervention. Demographic characteristics at baseline were similar for the three groups (Table 1).

Table 2 shows the absolute values for each variable, in all the groups, and no group × time interaction was detected ( $p > 0.05$ ).

There was no significant intergroup change in discomfort ( $F_{1,28} = 0.31$ ;  $p = 0.57$ ; power = 0.08) or during interventions ( $F_{9,20} = 0.73$ ;  $p = 0.68$ ; power = 0.25), as shown in Table 3. Similarly, the chi-squared test showed no statistically significant association between experimental groups and sensation (pleasantness/unpleasantness) during stretching,  $\chi^2(1) = 0.25$ ;  $P = 0.49$ . However, 81.8% of the SSg and 73.3% of the DSg reported a feeling of pleasantness/comfort when performing the maneuvers.

## Discussion

The present study compared the acute effects of a single hamstring SS and DS session and a 10-session stretching program, analyzing the following variables: ROM, neuromuscular performance, and functional performance in physically active and healthy subjects. The results demonstrate that, regardless of using static or dynamic techniques, a single or ten stretching sessions do not change the aforementioned variables. These findings do not confirm the initial hypothesis and raise an important question about using

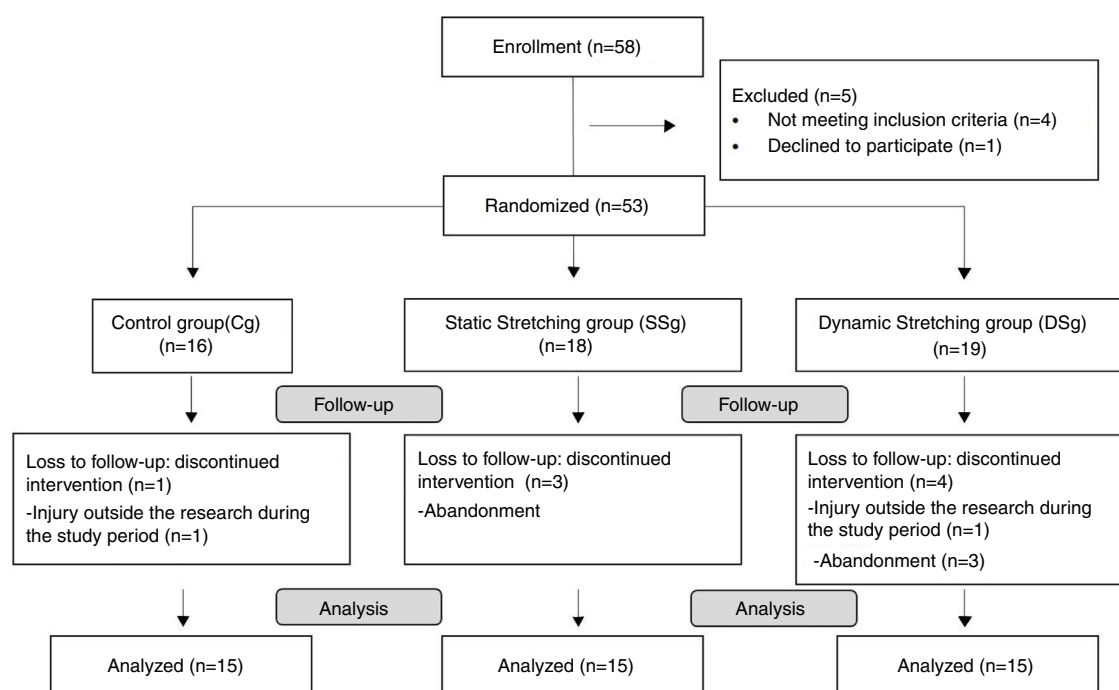


Figure 1 Flow diagram of volunteers throughout the study.

**Table 1** Anthropometric characteristics for the three groups.

	Groups		
	Control (n = 15)	Static (n = 15)	Dynamic (n = 15)
Age (years)	21.27 ± 2.8	23.07 ± 3.5	21.47 ± 3.0
Body mass (kg)	74.38 ± 9.2	68.07 ± 9.0	72.06 ± 8.2
Height (m)	1.76 ± 0.1	1.72 ± 0.1	1.74 ± 0.1
BMI (kg/m <sup>2</sup> )	23.94 ± 1.8	22.98 ± 2.7	23.68 ± 1.3

BMI, body mass index.

Data are expressed as mean ± SD.

self-stretching in clinical practice, since the results of the primary variable (ROM) do not corroborate those reported in the literature.

It is important to highlight that the stretching techniques and intensity used here were similar to those used in physical activity protocols (Bandy et al., 1998). In this study, all the subjects were instructed to perform the techniques until they felt mild discomfort. One of the possible explanations for the results is the self-stretching modality, whose intensity may have been underestimated by the subjects, indicating that they might have controlled the load applied to the maneuvers during interventions. This information is based on Feeling Scale data (Frazao et al., 2016) and absolute discomfort values for both experimental groups, suggesting that most participants remained in their "comfort zone" during interventions. Our findings demonstrate that comfort zone intensity is not the best strategy to increase long-term ROM.

According to Kubo et al. (2001), the magnitude of the force generated by the maneuver may produce a different tissue response, where applying a little force may result in little or no gain in ROM, while considerable force can damage the tissue, resulting in an inflammatory response. Moreover, there seems to be a relationship between maneuver intensity and duration. Guissard et al. (2001) and Guissard and Duchateau (2006) showed that prolonged stretching in the comfort zone may be related to a decline and modulation of the H reflex, thereby interfering in the pre-synaptic action of motoneurons, facilitating relaxation of the stretched muscle. Although the time used in the present study was similar to that applied in clinical practice, comfort zone intensity, associated with the short stretching time, may not have been enough to promote gains in ROM.

Another limiting factor of the present study was the assessment method, specifically for the SSg. Silveira et al. (2011) investigated the acute effects of static stretching on hamstring flexibility and observed an improvement in static flexibility, but no impact on its dynamic counterpart. In our protocol, the static self-stretching technique required muscle relaxation in the extended knee position during the interventions and active contraction of the quadriceps during assessment. As such, the non-specificity of the assessment method and intervention may have interfered in final ROM.

Likewise, there was no change in ROM for the DSg, which used active quadriceps contraction during assessments and interventions. According to Herman and Smith (2008), this is not the most appropriate technique for

increasing flexibility, although some authors (Samukawa et al., 2011) have reported acute changes in ROM after dynamic stretching. One of the possible explanations involves stretching speed, which may have favored activation of the myotatic reflex (Bandy et al., 1998), not relaxing the hamstrings. According to Samukawa et al. (2011), when dynamic stretching is performed slowly, muscle tone declines in the target muscle, resulting in increased ROM.

The information collected also contributed to the results obtained for the neuromuscular and functional performance variables analyzed in this study. Similarly, the acute responses of ML, passive peak torque, isokinetic fatigue index of knee extensors and flexors and countermovement vertical jump did not change, even after a 10-session stretching protocol. Marek et al. (2005) reported that changes due to stretching alter the viscoelastic properties of the motor unit, which could affect the muscle length tension curve and/or speed of the sarcomere stretch-shortening cycle. Additionally, decreased muscle activation, caused by reduced reflex excitability, could also be altered (Cramer et al., 2005). This is the most important factor, since changes in neural sensory pathways precede structural tissue modifications (Brasileiro et al., 2007). However, in this study, no positive and/or negative changes in performance variables were observed in any of the three moments following baseline after the use of both techniques.

Most authors who evaluated ML only investigated the acute effect of a single static stretching session using a passive modality. Moreover, other authors did not investigate the assessment method to determine muscle response after dynamic stretching. With respect to passive torque, Chan et al. (2001) showed no changes after 4- and 8-week static hamstring stretching programs, in contrast to Nakamura et al. (2012) and Gajdosik et al. (2007), who observed a decline after a short-term stretching program. These contradictory results may be due to changes in a number of factors, such as intensity (Konrad and Tilp, 2014), duration (Chan et al., 2001; Magnusson et al., 1996) and stretching modality (Weppler and Magnusson, 2010). There were also no changes in fatigue levels or countermovement vertical jump after either stretching technique, reinforcing the influence of self-stretching and dynamic intensity, which may not have been enough to produce positive and/or negative changes in performance.

In short, the results of the present study showed no changes in ROM or performance when subjects underwent 1 or 10 sessions of static or dynamic hamstring stretching.

**Table 2** Absolute values of pre 1st, post 1st, post 10th and 48 h for the three groups in all variables.

Variables	Pre-1st	Post-1st	Post-10th	48 h	Comparisons <sup>a</sup>
<i>ROM</i> (°)					Interaction ( $F_{6,126} = 2.08$ ; $p = 0.06$ ; $d = 0.31$ ; $power = 0.73$ )
Cg	139.33 ± 8.02	136.17 ± 8.16	138.76 ± 9.69	139.36 ± 10.74	
SSg	138.06 ± 11.24	139.74 ± 13.79	142.26 ± 13.38	140.18 ± 14.32	
DSg	135.08 ± 9.96	133.77 ± 9.89	140.52 ± 8.32	139.78 ± 10.30	
<i>ML</i> (ms)					Interaction ( $F_{6,126} = 1.07$ ; $p = 0.39$ ; $d = 0.22$ ; $power = 0.40$ )
Cg	48.00 ± 29.80	48.67 ± 24.74	40.67 ± 28.40	35.33 ± 27.22	
SSg	46.67 ± 13.45	48.00 ± 24.55	42.00 ± 24.55	48.67 ± 18.84	
DSg	47.33 ± 20.16	44.00 ± 8.28	50.67 ± 23.44	36.00 ± 17.64	
<i>pPT/BM</i> (Nm/kg)					Interaction ( $F_{6,126} = 0.35$ ; $p = 0.91$ ; $d = 0.13$ ; $power = 0.14$ )
Cg	48.01 ± 7.04	50.62 ± 7.45	48.44 ± 9.64	48.53 ± 6.07	
SSg	57.53 ± 14.67	59.33 ± 16.90	56.22 ± 14.50	54.82 ± 16.53	
DSg	51.35 ± 11.23	53.14 ± 9.85	52.90 ± 8.85	51.02 ± 6.73	
<i>Fl<sub>Ext</sub></i> (%)					Interaction ( $F_{6,120} = 1.02$ ; $p = 0.41$ ; $d = 0.22$ ; $power = 0.39$ )
Cg	45.54 ± 3.55	44.78 ± 3.72	44.16 ± 4.17	44.68 ± 5.05	
SSg	47.71 ± 4.75	45.42 ± 5.07	46.02 ± 3.87	45.74 ± 3.69	
DSg	47.78 ± 5.37	47.10 ± 2.67	44.50 ± 4.73	44.54 ± 2.40	
<i>Fl<sub>FLEX</sub></i> (%)					Interaction ( $F_{6,126} = 0.45$ ; $p = 0.84$ ; $d = 0.14$ ; $power = 0.18$ )
Cg	47.33 ± 6.94	45.45 ± 6.03	43.06 ± 6.28	42.96 ± 4.70	
SSg	49.70 ± 7.25	46.75 ± 11.08	47.58 ± 7.28	45.61 ± 8.15	
DSg	47.32 ± 7.71	45.98 ± 4.44	45.33 ± 5.37	44.01 ± 3.61	
<i>VJ/BM</i> (cm/kg)					Interaction ( $F_{6,126} = 1.22$ ; $p = 0.30$ ; $d = 0.24$ ; $power = 0.46$ )
Cg	0.49 ± 0.11	0.50 ± 0.10	0.49 ± 0.09	0.50 ± 0.10	
SSg	0.56 ± 0.11	0.57 ± 0.11	0.56 ± 0.10	0.56 ± 0.11	
DSg	0.51 ± 0.08	0.51 ± 0.08	0.53 ± 0.07	0.52 ± 0.07	

Cg, control group; SSg, static stretching group; DSg, dynamic stretching group; ROM, range of motion; ML, muscle latency; pPT/BM, passive peak torque normalized by body mass; Fl<sub>EXT</sub>, fatigue index of knee extensor muscles at 240°/s; Fl<sub>FLEX</sub>, fatigue index of knee flexor muscles at 240°/s; VJ/BM, height of countermovement vertical jump normalized by body mass. Values expressed as mean ± SD.

<sup>a</sup> Group × time interaction values ( $F$ -test,  $p$  value, Cohen's  $d$  coefficient and power).

**Table 3** Self-reported discomfort immediately after each stretching session.

Groups	Sessions									
	1	2	3	4	5	6	7	8	9	10
SSg	60.4 ± 22.3	56.0 ± 17.6	59.9 ± 18.2	52.9 ± 18.6	53.9 ± 21.3	54.0 ± 20.3	52.2 ± 21.2	52.7 ± 22.3	54.7 ± 25.1	54.1 ± 24.8
DSg	62.2 ± 25.6	62.5 ± 25.5	59.3 ± 25.4	53.1 ± 28.0	60.5 ± 22.3	61.4 ± 25.0	62.4 ± 20.8	57.7 ± 22.6	54.1 ± 22.2	59.0 ± 26.7
Effect size <sup>a</sup>	<i>d</i> =0.07	<i>d</i> =0.25	<i>d</i> =0.02	<i>d</i> =0.01	<i>d</i> =0.29	<i>d</i> =0.29	<i>d</i> =0.49	<i>d</i> =0.22	<i>d</i> =0.02	<i>d</i> =0.19

SSg, static stretching group; DSg, dynamic stretching group.

Data are expressed as mean ± SD.

<sup>a</sup> Cohen's *d* coefficient between groups for each stretching session.

The static or dynamic self-stretching applied in this study may be feasible for maintaining flexibility, without changing performance. The findings reported here can serve as a warning to health professionals involved in stretching exercises to pay attention to the parameters used during the maneuvers, especially intensity. It is suggested that the same protocol be adopted in future studies and applied to different populations and muscle groups, using longer interventions (>12 weeks). Moreover, our results raise another question: what is the influence of different self-stretching (SS) intensities and DS speeds (slow, progressive and rapid) on improved ROM and performance when conducted within a stretching program?

## Conclusion

Neither a single session of hamstring static or dynamic stretching nor a 10-session stretching program affected ROM, neuromuscular or functional performance. The results of this study demonstrate the importance of quantitatively controlling the intensity of stretching maneuvers, which is subjectively reported in most studies.

## Funding

The present study did not receive any financial support.

## Conflicts of interest

The authors declare no conflicts of interest.

## Acknowledgments

This work was supported by the Brazilian Council for Scientific and Technological Development (CNPq 2014-2016).

## References

- Amiri-Khorasani M, Kellis E. *Static vs. dynamic acute stretching effect on quadriceps muscle activity during soccer instep kicking.* *J Hum Kinet* 2013;39:37–47.
- Apostolopoulos N, Metsios GS, Flouris AD, Koutedakis Y, Wyon MA. *The relevance of stretch intensity and position – a systematic review.* *Front Psychol* 2015;6:1128.
- Aquino CF, Freire MTF, Neves NM, Ferreira PCA, Fonseca ST. *Análise da confiabilidade de um método de mensuração do ângulo de pico de torque ativo dos isquiossurais.* *Rev Bras Fisioter* 2007;11:169–75.
- Attia A, Dhahbi W, Chaouachi A, Padulo J, Wong DP, Chamari K. *Measurement errors when estimating the vertical jump height with flight time using photocell devices: the example of Optojump.* *Biol Sport* 2017;34:63–70.
- Bandy WD, Irion JM, Briggler M. *The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles.* *J Orthop Sports Phys Ther* 1998;27:295–300.
- Bandy WD, Irion JM, Briggler M. *The effect of time and frequency of static stretching on flexibility of the hamstring muscles.* *Phys Ther* 1997;77:1090–6.
- Barbosa GM, Santos HH, Dantas GAF, Silva BR, Pinheiro SM, Brito Vieira WH. *Intra-rater and inter-instrument reliability on range of movement of active knee extension.* *Motriz* 2017;23:53–9.
- Bazett-Jones D, Gibson M, McBride J. *Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching.* *J Strength Cond Res* 2008;22:25–31.
- Beck TW. *The importance of a priori sample size estimation in strength and conditioning research.* *J Strength Cond Res* 2013;27:2323–37.
- Behm DG, Blazevich AJ, Kay AD, McHugh M. *Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review.* *Appl Physiol Nutr Metab* 2016;41:1–11.
- Biodex System 3 Pro. *Manual – applications/operations; 2002.* p. 32–5.
- Brasileiro JS, Faria A, Queiroz LL. *Influence of cooling and heating in the flexibility of hamstring muscles.* *Braz J Phys Ther* 2007;11:1–5.
- Bruton A, Conway JH, Holgate ST. *Reliability: what is it, and how is it measured?* *Physiotherapy* 2000;86:94–9.
- Chan SP, Hong Y, Robinson PD. *Flexibility and passive resistance of hamstrings of young adults using two different static stretching protocols.* *Scand J Med Sports* 2001;11:81–6.
- Cohen J. *Statistical power analysis for the behavioral sciences.* L. Erlbaum Associates; 1988.
- Costa PB, Herda TJ, Herda AA, Cramer JT. *Effects of dynamic stretching on strength, muscle imbalance, and muscle activation.* *Med Sci Sports Exerc* 2014;46:586–93.
- Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. *International physical activity questionnaire: 12-country reliability and validity.* *Med Sci Sports Exerc* 2003;35:1381–95.
- Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, Beck TW. *Acute effects of static stretching on peak torque in women.* *J Strength Cond Res* 2004;18:236–44.
- Cramer JT, Housh TJ, Weir JP, Johnson GO, Coburn JW, Beck TW. *The acute effects of static stretching on peak torque, mean power output, electromyography and mechanomyography.* *Eur J Appl Physiol* 2005;93:530–9.
- Curry BS, Chengkalath D, Crouch GJ, Romance M, Manns PJ. *Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women.* *J Strength Cond Res* 2009;23:1811–9.



- De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech* 1997;13:135–63.
- Esposito F, Ce E, Rampichini S, Veicsteinas A. Acute passive stretching in a previously fatigued muscle: electrical and mechanical response during tetanic stimulation. *J Sports Sci* 2009;27:1347–57.
- Frazao DT, Farias Junior LF, Dantas TCB, Krinski K, Elsangedy HM, Prestes J, et al. Feeling of pleasure to high-intensity interval exercise is dependent of the number of work out bouts and physical activity status. *PLOS ONE* 2016; 11:e0152752.
- Gajdosik RL, Allred JD, Gabbert HL, Sonsteng BA. A stretching program increases the dynamic passive length and passive resistive properties of the calf muscle-tendon unit of unconditioned younger women. *Eur J Appl Physiol* 2007; 99:449–54.
- Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuro-motor fitness in apparently healthy adults. *Med Sci Sport Exerc* 2011;43:1334–59.
- Guissard N, Duchateau J. Neural aspects of muscle stretching. *Exerc Sport Sci Rev* 2006;34:154–8.
- Guissard N, Duchateau J, Hainaut K. Mechanisms of decreased motoneurone excitation during passive muscle stretching. *Exp Brain Res* 2001;137:163–9.
- Johnson AW, Mitchell UH, Meek K, Feland JB. Hamstring flexibility increases the same with 3 or 9 repetitions of stretching held for a total time of 90s. *Phys Ther Sport* 2014; 15:101–5.
- Habets B, Staal JB, Tjissen M, Van Cingel R. Intrarater reliability of the human NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. *BMC Res Notes* 2018;11:15.
- Hardy CJ, Rejeski WJ. Not what, but how one feels: the measurement of affect during exercise. *J Sport Exerc Psychol* 1989;11:204–317.
- Herman SL, Smith DT. Four-week dynamic stretching warm up intervention elicits longer-term performance benefits. *J Strength Cond Res* 2008;22:1286–97.
- Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 2000; 10:361–74.
- Kay AD, Blazevich AJ. Effect of acute static stretch on maximal muscle performance: a systematic review. *Med Sci Sports Exerc* 2012;44:154–64.
- Kenny IC, Cairealláin AO, Comyns TM. Validation of an electronic jump mat to assess stretch shortening cycle function. *J Strength Cond Res* 2012;26:1601–8.
- Kokkonen J, Nelson AG, Eldredge C, Winchester JB. Chronic static stretching improves exercise performance. *Med Sci Sports Exerc* 2007;39:1825–31.
- Konrad A, Tilp M. Increased range of motion after static stretching is not due to changes in muscle and tendon structures. *Clin Biomech* 2014;29:636–42.
- Kubo K, Kanehisa H, Kawakami Y, Fukunaga T. Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *J Appl Physiol* 2001;90:520–7.
- Li L, Liu X, Herr K. Postoperative pain intensity assessment: a comparison of four scales in Chinese adults. *Pain Med* 2007;8: 223–34.
- Magnusson P, Renström P. The European College of Sports Sciences Position statement: the role of stretching exercises in sports. *Eur J Sport Sci* 2006;6:87–91.
- Magnusson SP, Simonsen EB, Aagaard P, Sørensen H, Kjaer M. A mechanism for altered flexibility in human skeletal muscle. *J Physiol* 1996;15:291–8.
- Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, et al. Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. *J Athl Train* 2005;40:94–103.
- McHugh MP, Nesse M. Effect of stretching on strength loss and pain after eccentric exercise. *Med Sci Sports Exerc* 2008; 40:566–73.
- Meerits T, Bacchieri S, Pääsuke M, Erelina J, Cicchella A, Gapeyeva H. Acute effect of static and dynamic stretching on tone and elasticity of hamstring muscles and on vertical jump performance in track-and-field athletes. *Acta Kinesiol Univers Tart* 2014;20:48–59.
- Nakamura M, Ikezoe T, Takeno Y, Ichihashi N. Effects of a 4-week static stretch training program on passive stiffness of human gastrocnemius muscle-tendon unit in vivo. *Eur J Appl Physiol* 2012;112:2749–55.
- Nogueira JFS, Lins CAA, Souza AVC, Brasileiro JS. Efeitos do aquecimento e do alongamento na resposta neuromuscular dos isquiotibiais. *Rev Bras Med Esp* 2014;20:262–6.
- Rose EA, Parfitt G. Can the feeling scale be used to regulate exercise intensity? *Med Sci Sports Exerc* 2008;40:1852–60.
- Samukawa M, Hattori M, Sugama N, Takeda N. The effects of dynamic stretching on plantar flexor muscle-tendon tissue properties. *Man Ther* 2011;16:618–22.
- Silveira G, Sayers M, Waddington G. Effect of dynamic versus static stretching in the warm-up on hamstring flexibility. *Sport J* 2011;3:1–9.
- Souza RH, Greco CC, Denadai BS. A taxa de desenvolvimento de força durante contrações isocinéticas dos extensores do joelho não é afetada pelo alongamento estático em indivíduos ativos. *Rev Bras Ciênc Esporte* 2015;37:400–6.
- Thomas S, Reading J, Shephard RJ. Revision of the physical activity readiness questionnaire (PAR-Q). *Can J Sport Sci* 1992;17:338–45.
- Weppler CH, Magnusson SP. Increasing muscle extensibility: a matter of increasing length or modifying sensation? *Phys Ther* 2010;90:438–49.
- Worrell TW, Smith TL, Winegardner J. Effect of hamstring stretching on hamstring muscle performance. *J Orthop Sports Phys Ther* 1994;20:154–9.
- Yamaguchi T, Ishii K. Short review article an optimal protocol for dynamic stretching to improve explosive performance. *J Phys Fit Sports Med* 2014;3:121–9.