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The acute effects of static stretching on peak force, peak rate of force development and muscle activity during single- and multiple-joint actions in older women

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Abstract

The present study investigated the acute effects of static stretching on peak force, peak rate of force development and integrated electromyography (iEMG) in 27 older women (65 ± 4 years; 69 ± 9 kg; 157 ± 1 cm; 28 ± 4 kg $\cdot$ m^{-2}). The participants were tested during two exercises (leg press and knee extension) after two conditions: stretching and control. The data were collected on four days (counterbalanced with a 24-hour rest period). In the stretching condition, the quadriceps muscle was stretched (knee flexion) for three sets of 30 s with 30 s rest intervals. No significant difference was detected for peak force and peak rate of force development during the single- and multiple-joint exercises, regardless of the following interactions: condition (stretching and control) vs. time (pre x post x 10 x 20 x 30 minutes post; $P > 0.05$) and exercise vs. time ($P > 0.05$). Additionally, no significant interaction was found for the iEMG activity (condition vs. time; $P > 0.05$) in the single- and multiple-joint exercises. In conclusion, a small amount of stretching of an agonist muscle (quadriceps) did not affect the peak force, peak rate of force development and EMG activity in older women during single- and multiple-joint exercises.

Keywords: *aging, warm-up, isometric force-time curve, performance*

Introduction

The potential effects of prior static stretching on performance in strength exercises are controversial. Some research has demonstrated that in young adults, static stretching can induce a transient reduction in both isometric and dynamic actions. In contrast, other studies failed to detect changes in muscle strength after different stretching routines in young participants (Herda, Cramer, Ryan, McHugh, & Stout, 2008; Molacek, Conley, Evetovich, & Hinnerichs, 2010; Sekir, Arabaci, Akova, & Kadagan, 2010). These contradictions may be partially explained by differences in the stretching protocols and the strategies used to assess muscle strength.

For example, the isometric force during single- and multiple-joint actions has been shown to be differentially affected by previous quadriceps stretching (McBride, Deane, & Nimphius, 2007), whereby the peak force declines during a single-joint action (knee extension), and a significant reduction is only observed in the rate of force development in a multiple-joint action (squat). The reciprocal inhibition of antagonist muscles has been suggested to be based on the amount of agonist muscle activity (Crone, 1993; McBride et al., 2007). Transient decreases in muscle activation, as assessed by electromyography (EMG), have been previously reported (Avela, Finni, Liikavainio, Niemela, & Komi, 2004; Fowles, Sale, & MacDougall, 2000). Thus, any change in agonist activity may have a magnified effect on decreasing antagonist muscle activity through a reflex loop (Crone, 1993). Therefore, measuring the biceps femoris activity whenever the quadriceps muscle has been previously stretched would be important.

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Notably, most studies showing strength decline after stretching tested single-joint exercises (Egan, Cramer, & Massey, 2006; Fowles et al., 2000; Herda et al., 2008; Knudson & Noffal, 2005; Nelson, Allen, Cornwell, & Kokkonen, 2001; Power, Behm, Cahill, Carrol, & Young, 2004), and data regarding multiple-joint actions appear to be lacking. The influence of stretching on multiple-joint dynamic strength activities has resulted in controversial results (Fowles et al., 2000; Herda et al., 2008; Knudson & Noffal, 2005; Nelson et al., 2001; Power et al., 2004). Furthermore, we could only identify one investigation reporting a significant effect of stretching on the multiple-joint isometric maximal force output (Bazzet-Jones, Winchester, & McBride, 2005).

In addition, the total time of muscle stretching may have important implications because there is a dose-response effect between the stretch duration and the magnitude of the decrements in force production (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). A small amount of stretching can be expected to not negatively influence the muscle force output. Recently, two systematic reviews reported that stretching between 60 and 90 seconds was sufficient to promote decreases in force production (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). These findings have practical relevance because static stretching routines lasting between 30 and 120 seconds are recommended prior to muscle-strengthening activities (American College of Sports Medicine [ACSM], 2007).

The stretching-induced muscle strength deficit has not been systematically investigated in older subjects. During the aging process, changes in neuromuscular function (e.g., neural activation and tendon mechanical properties) are associated with reductions in both peak force and rate of force development (Klass, Baudry, & Duchateau, 2008; Narici & Maganaris, 2007). This effect is particularly important in women because they present a greater decline in muscle quality in the lower limbs compared to the upper limbs (Lynch et al., 1999). Behm et al. (2006) have suggested that a muscle-tendon unit with reduced stiffness may more successfully accommodate the stress associated with an acute bout of stretching. Thus, older subjects may respond differently than young individuals to static stretching, and a small amount of stretching may not be sufficient to promote decreases in force production (Handrakis et al., 2010; Magnusson, 1998). Some previous studies failed to demonstrate stretching-induced strength reductions in elderly participants (Gurjão, Carneiro, Gonçalves, Moura, & Gobbi, 2010; Handrakis et al., 2010). To our knowledge, only one study found a significant decline in peak force and peak rate of force development after static stretching in older women, with no change in EMG activity (Gurjão, Gonçalves, Moura, & Gobbi, 2009). The lack of information about the influence of previous stretching on the strength performance in older populations warrants additional investigation.

Therefore, the present study aimed to investigate the acute effects of static stretching on peak force, peak rate of force development and integrated EMG (iEMG) activity in older women during single- and multiple-joint actions. Thus, the following hypotheses were evaluated: a) the peak force and peak rate of force development of older women would not decrease after a small amount of static stretching and no change in muscle iEMG activity would occur; b) the isometric peak force and peak rate of force development during single- and multiple-joint exercises should be differentially influenced by previous static stretching.

Methods

Experimental approach to the problem

Each participant visited the laboratory six times, with an interval of 24 hours between visits. On the first visit, the following procedures were performed: a) familiarisation with the isometric exercises during the single- and multiple-joint actions; b) familiarisation with the static stretching exercise; and c) anthropometric measurements. The participants were asked to identify and report the onset of pain during the knee flexion exercise. On the second visit, these procedures were repeated, and the electrode placement used to record the EMG activity was determined.

On the four subsequent visits, the peak force and peak rate of force development were assessed during isometric knee extension and leg press performed after either the stretching or control condition. Only one of four experimental protocols was performed on each day. The order of each exercise and condition was determined by balanced cross-over randomisation. After placing the electrodes to record EMG activity, the participants performed three maximal isometric contractions to determine the baseline peak force and peak rate of force development (pre-values) for the specific exercise. After 10 min, the exercise was performed following one of the two conditions (stretching or control). The peak force and peak rate of force development data were measured immediately after the condition (post-condition) and 10, 20 and 30 min later (Figure 1).

In the control condition, the participants rested in a prone position on a barrow for a similar time as that used in the stretching routine ($\sim$2.5 min). As aforementioned, all participants were familiarised with the static stretching routine before the experimental sessions. In the stretching condition, the

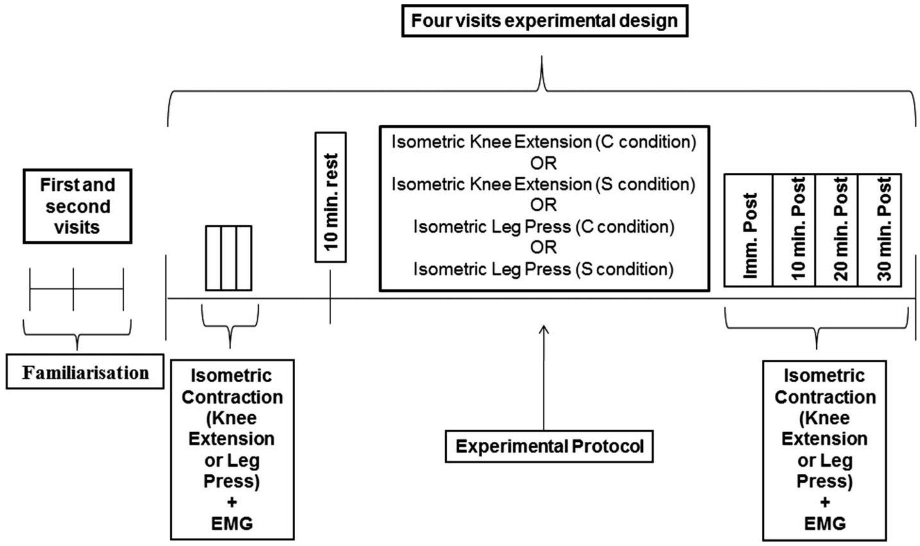

Figure 1. Summary of experimental design. C = control; S = stretching.

quadriceps muscle was stretched (knee flexion) to the maximal range of motion in three sets of 30 s separated by 30 s intervals. The participants were placed in a prone position on a barrow, and the knee of the dominant limb was flexed by the examiner. The maximum range of motion was determined as the point where the participant reported the onset of a pain sensation.

All procedures were conducted at the same time of day to minimise possible circadian variations in muscle strength. Until the completion of the experimental protocol, the participants were instructed not to perform physical activities during the 24 h prior to the visits.

Participants

Initially, 60 older women who participated in a physical activity programme (muscle endurance and walking performed three times per week for at least three months) volunteered to participate in the study. The following exclusion criteria were applied: bone, joint or muscle impairments that could limit the execution of the exercises and cardiovascular or metabolic disease, especially hypertension and diabetes. After a clinical examination, a total of 27 women (65 ± 4 years; 69 ± 9 kg; 157 ± 1 cm; 28 ± 4 kg $\cdot$ m^{-2}) were enrolled in the experimental protocol. The study was approved by the institutional ethical board, and informed consent was obtained prior to participation, as recommended by the Helsinki Convention.

Force-time curve assessment

The participants were instructed to reach the maximal values of peak force "as fast as possible" and to sustain this level until the examiner said to stop. The entire exertion lasted 5 s; approximately 2 s to reach the maximal values and approximately 3 s to sustain. As soon as the test began, the participants were verbally encouraged to perform their maximum effort and received visual feedback on their peak force performance. Each participant performed the test three times, with a recovery interval of 3 to 5 min between each trial.

The force transducer signal was acquired using an analogue signal amplifier (model CS 800 AFTM, EMG system^{TM}, SP, Brazil) with a sampling frequency of 2000 Hz, and this signal was then synchronised to all EMG signal recordings. The recorded signal was stored on a hard disk for subsequent analysis. The raw signal from the force transducer was filtered digitally by a fourth-order, zero-lag Butterworth low-pass filter using a cut-off frequency of 15 Hz. The onset of the contraction was defined as the point at which the measured resistance value exceeded 7.5 N above baseline (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). The peak force was determined as the highest value registered within the one-second window (500–1500 ms) that corresponded to the onset of the muscle contraction in each trial (Häkkinen et al., 2001). The peak rate of force development was determined by the steepest slope of the curve, which was calculated within regular windows of 20 ms (ΔForce/ΔTime), for the first 200 ms after the onset of the contraction (Aagaard et al., 2002).

Single-joint action

The unilateral isometric knee extension was assessed using a knee extension chair. The participants remained seated with their hip and knee positioned at 90°. The knee joint centre was aligned with the rotation axis dynamometer. The lever arm of the dynamometer was positioned just above the lateral malleolus. Ankle protection was used to prevent any discomfort caused by the support equipment during the maximum contraction procedure.

Multiple-joint action

The bilateral isometric knee and hip extension were assessed using a device consisting of a metal frame, as described elsewhere (Sahaly, Vandewalle, Driss, & Monod, 2001), which utilised the adjustment of the sliding seat knee angle (90°). The hip joint angle was fixed at 110°. The leg press consisted of a foot platform fixed to a frame that made contact with a force transducer (model 2000 NTM, EMG system^{TM}, SP, Brazil). The hip was fixed, and the participants were allowed to stabilise their upper body by holding onto handles attached to the leg press.

Electromyography assessment

All biological signals were recorded according to the International Society of Electrophysiology and Kinesiology (ISEK) standard recommendations (Merlleti, 1999) using an 8-channel module (model CS 800 AFTM, EMG system^{TM}, SP, Brazil) with a band pass filter using cut-off frequencies of 20–500 Hz, an amplifier gain of 1000X, and a common mode rejection ratio >120 dB. A converting plate for the analogical/digital (A/D) 12-bit signal was used to convert the analogue signals to digital signals using a sampling frequency of 2000 Hz for each channel and an input range of 5 mV (de Andrade et al. 2005). The electrode placement on the anatomical points followed the SENIAM (Surface Electromyography for the Non–Invasive Assessment of Muscles) standards (Hermens, Freriks, Disselhorst–Klug, & Rau, 2000). Bipolar surface electrodes (diameter: 10 mm; centre-to-centre distance: 23 mm) were placed over the agonist vastus medialis, vastus lateralis and biceps femoris of the right leg. The longitudinal axes of the electrodes were in line with the presumed direction of the underlying muscle fibres. All electrode positions were carefully measured to ensure identical pre- and post-training recording sites. The electrode placement locations were shaved and cleaned with an abrasive cream and alcohol, and electrolytic gel was applied to the electrode surface.

The EMG signal was digitally filtered using a high-pass, fourth-order, zero-lag Butterworth filter with a 5 Hz cut-off frequency, followed by a moving root-mean-square filter with a 50 ms time constant (Aagaard et al., 2002). The iEMG activity was defined as the area under the curve of the rectified EMG signal, i.e., the mathematical integral of the raw EMG signal. The iEMG was determined for the different parameters of the isometric force-time curve. The onset of EMG integration was initiated 70 ms before the individual onset of the contraction to account for the presence of electromechanical delay (Aagaard et al., 2002). The iEMG activity for the peak force was determined within the one-second window (500–1500 ms) corresponding to the onset of muscle contraction (Häkkinen et al., 2001).

Statistical analysis

Descriptive statistics (mean and standard deviation) were used. Data normality was confirmed by the Shapiro-Wilk test, and a two-way analysis of variance (ANOVA) for repeated measures was applied to compare the peak force and peak rate of force development between the experimental conditions (stretching x control) and times tested (pre x post x 10 x 20 x 30 min post). The peak force and peak rate of force development values were normalised according to the baseline peak force, and a comparison between exercises (single- and multiple-joint) at various times (pre x post x 10 x 20 x 30 min post) was also conducted using a two-way ANOVA for repeated measures. Tukey's post-hoc test was applied to determine the pair-wise differences when significant F ratios were obtained.

The intra-class correlation coefficient (R) was used to test the reliability of the peak force measurement under the two experimental conditions (stretching and control) for both exercises. The effect sizes (ES) were calculated by dividing the difference between the mean values associated with each comparison by the pooled standard deviation. A probability level of $P \leq 0.05$ was adopted for statistical significance, and all calculations were performed using the same statistical software (Statistica 7.0^{TM}, Statsoft, OK, USA).

Results

The intra-class correlation coefficients (R) obtained for peak force during the single-and multiple-joint actions were 0.86 (95% confidence interval [CI]; 0.70–0.94) and 0.88 (95% CI; 0.73–0.94), respectively.

No stretching effect on peak force was observed for either the single- or multiple-joint actions ($P = 0.42$ and $P = 0.40$, respectively). However, there was a time effect for both exercises ($P = 0.01$; single-joint action: ES $= 0.26$, multiple-joint action: ES $= 0.33$) (Figure 2). The peak force was significantly lower compared to the baseline value at all time points, except for the 10th min following the single-joint action (Figure 2A) and immediately after the end of the multiple-joint action (Figure 2B) for the control condition.

No interaction between exercise x time ($P = 0.80$) was observed under the stretching condition. However, a time effect was observed under the control condition ($P = 0.01$, ES = 0.10), as there was a significant decrease detected at the 20 min and 30 min recovery points in comparison to the baseline (Figure 3).

No significant differences were detected for the iEMG activity of the vastus medialis, vastus lateralis and biceps femoris during the peak force in both exercises after the stretching or control conditions ($P > 0.05$) (Figure 4). In contrast, a significant time effect on the iEMG activity of the vastus medialis and vastus lateralis ($P = 0.02$, ES = 0.08 and $P = 0.01$, ES = 0.10, respectively) was detected during the multiple-joint action under both the stretching and control conditions.

The peak rate of force development values obtained under the stretching and control conditions over time for both exercises are presented in Figure 5. No significant interaction between condition x time was observed for the single- or multiple-joint actions ($P = 0.52$ and $P = 0.08$, respectively), which indicated no stretching effect. However, a time effect for both exercises ($P = 0.04$, ES = 0.06 and $P = 0.01$, ES = 0.20, respectively) was detected. The peak rate of force development decreased significantly compared to the baseline value at all time points under the stretching condition for the multiple-joint action (Figure 5B). The comparison of the normalised peak rate of force development values between exercises is shown in Figure 6. No significant interaction between exercise x time ($P = 0.40$) was observed under the stretching and control conditions.

Discussion

This study investigated the acute effects of static stretching on peak force, peak rate of force development and muscle activity in older women during

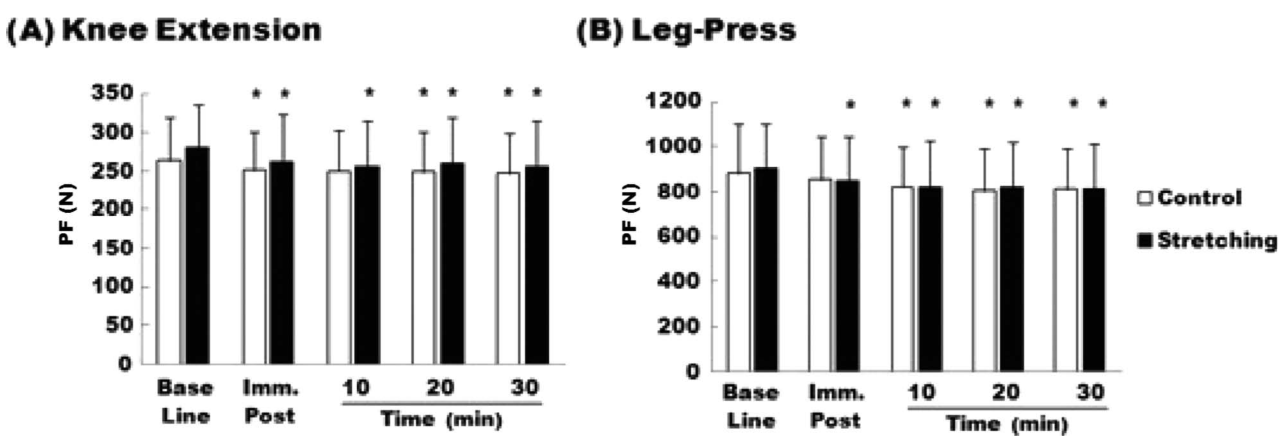

Figure 2. Peak Force (PF) during isometric Knee Extension (A) and Leg-Press (B) after the control and stretching conditions. The presented time points are baseline (pre-condition), immediately post-condition (Imm. Post), 10, 20 and 30 minutes post condition. *Significant decrease from baseline moment ($P < 0.05$). Values are expressed as means plus s ($n = 27$).

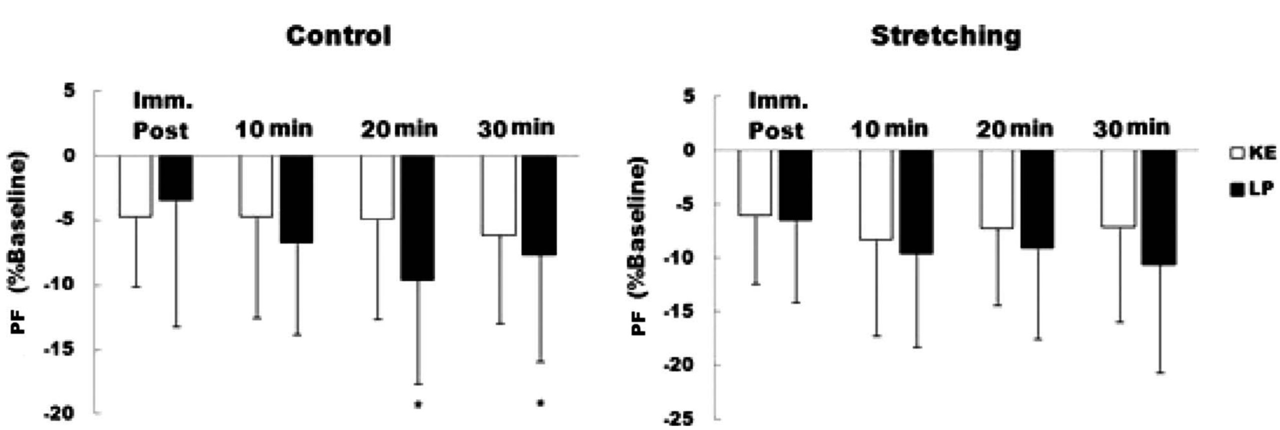

Figure 3. Comparison of Peak Force (PF) per cent change between isometric Knee Extension (KE) and Leg-Press (LP) after the control and stretching conditions. The presented time points are immediately post-condition (Imm. Post), 10, 20 and 30 minutes post condition. *Significant decrease from baseline moment ($P < 0.05$). Values are expressed as means minus s ($n = 27$).

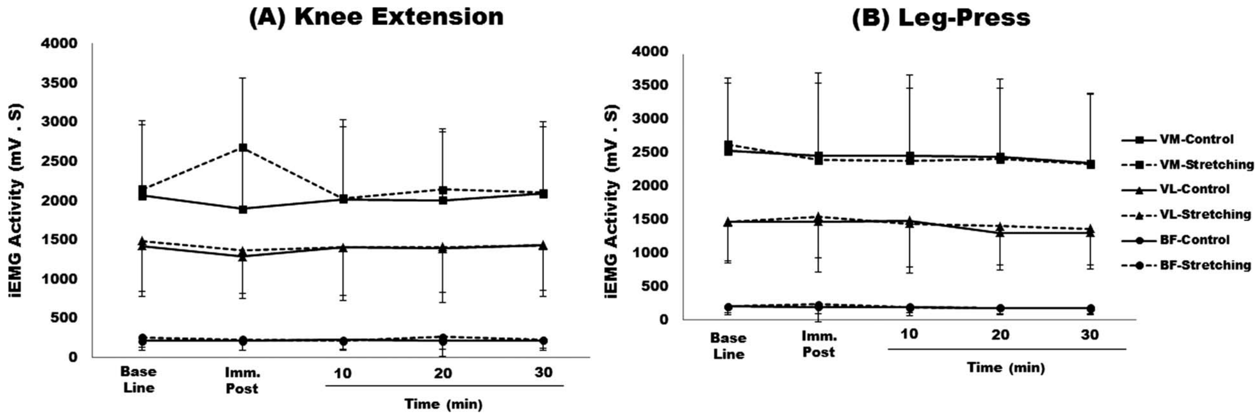

Figure 4. Integrated electromyographic (iEMG) activity of vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) during isometric Knee Extension (A) and Leg-Press (B) after the control and stretching conditions. The presented time points are baseline (pre-condition), immediately post-condition (Imm. Post), 10, 20 and 30 minutes post condition. Values are expressed as means plus or minus *s* ($n = 27$).

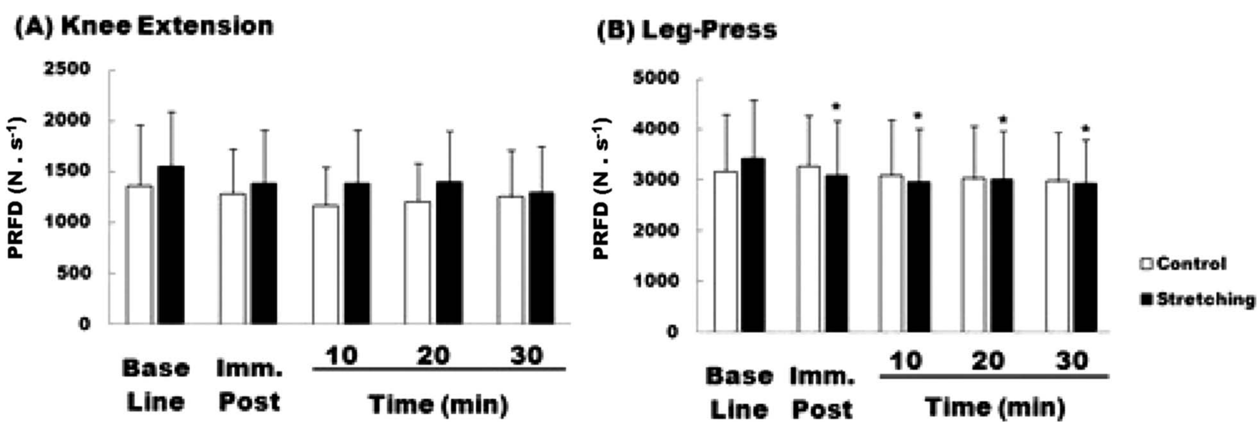

Figure 5. Peak Rate of Force Development (PRFD) during isometric Knee Extension (A) and Leg Press (B) after the control and stretching conditions. The presented time points are baseline (pre-condition), immediately post-condition (Imm. Post), 10, 20 and 30 minutes post condition. *Significant decrease from baseline moment ($P < 0.05$). Values are expressed as means plus *s* ($n = 27$).

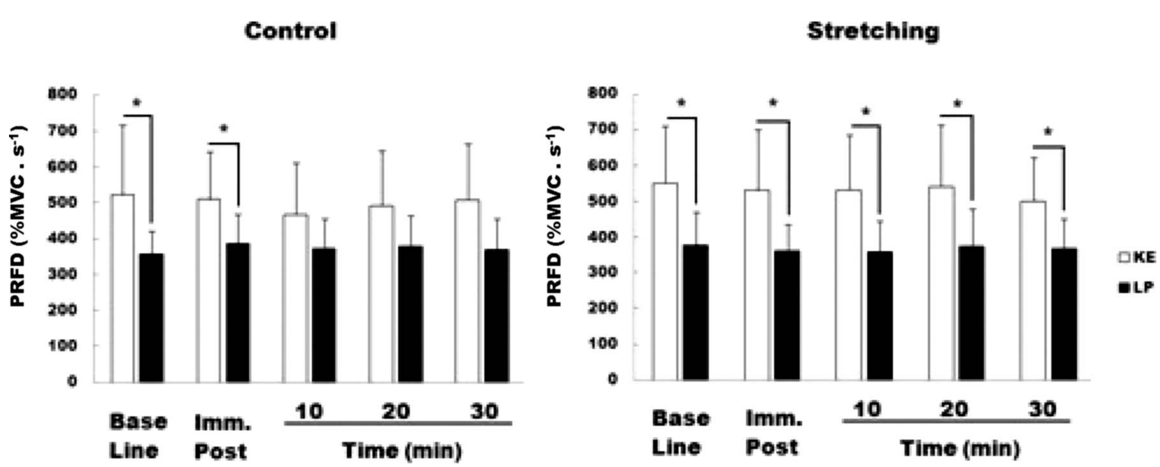

Figure 6. Comparison of Peak Rate of Force Development (PRFD) between isometric Knee Extension (KE) and Leg-Press (LP) after the control and stretching conditions. The presented time points are immediately post-condition (Imm. Post), 10, 20 and 30 minutes post condition. *Significant difference between KE and LP ($P < 0.05$). Values are expressed as means plus *s* ($n = 27$).

single- and multiple-joint actions. The results indicated that a small amount of stretching of an isolated agonist muscle (quadriceps) did not influence isometric force-time variables in older women.

The total stretching time may influence the strength performance (Kay & Blazevich, 2012), as previous studies have indicated a dose-response relationship between stretching volume and strength deficit (Ogura, Miyahara, Naito, Katamoto, & Aoki, 2007; Ryan et al., 2008; Siatras, Mittas, Mameletzi, & Vamvakoudis, 2008). In young adults, for example, decreases in the peak force after 30 and 60 s of quadriceps static stretching (8.5% and 16.0%, respectively) have been reported (Siatras et al., 2008).

Our stretching protocol may not have induced a strength deficit because of the low volume applied. However, it is important to mention that the total volume used in our stretching protocol was selected because it was in accordance with international recommendations for older adults (3 sets of 30 seconds each) (ACSM, 2007). Therefore, the current recommendations regarding static stretching for this population appear to have no effect on the performance of isometric muscle strength, at least when only one muscle group is stretched. Thus, further studies testing higher stretching volumes and different muscle groups, particularly in the elderly, should be performed.

Another important issue to consider when analysing the effect of static stretching on strength performance in multiple-joint actions is that such a performance depends on several muscle groups. Hence, the number of stretched muscle groups relative to those muscle groups that are activated during the exercise should be taken into account. For example, a previous study showed significant reductions in the peak force and peak rate of force development in older women during multiple-joint actions after stretching each major muscle group in the lower limbs (Gurjão et al., 2009). In contrast, no significant changes in the peak force and peak rate of force development were detected when only the quadriceps muscle was stretched (Gurjão et al., 2010). In the present study, where only the quadriceps muscle was stretched, the antagonist muscles may have compensated for the decrease in the force production capacity of the stretched musculature. Therefore, stretching only the quadriceps muscle did not influence the force output during the multiple-joint exercise.

Two mechanisms have been proposed to explain the muscle strength deficit mediated by stretching: a) a structural mechanism involving changes in the muscle-tendon unit stiffness and compliance and b) a neural mechanism involving a decrease in muscle activation. Furthermore, tendon compliance and stiffness have been correlated with peak force and rate of force development performance (Edmund & Josephson, 2007; Kubo, Kanehisa, Kawakami, & Fukunaga, 2001; Wilson, Murphy, & Pryor, 1994), and a significant relationship between the muscle-tendon unit compliance and isometric muscle strength has been reported (Wilson et al., 1994). Thus, a stiffer muscle-tendon unit would be more efficient during the initial transmission of force, thereby increasing the rate of force development.

Stretching can elicit negative effects on the ability of the muscle to produce force if there is a change in the stiffness of the muscle-tendon unit (particularly decreased tendon stiffness) (Kay & Blazevich, 2009; Kubo et al., 2001). A more compliant tendon allows the muscle to operate at a shorter length, which directly affects the length-tension relationship (Kay & Blazevich, 2009). In this study, the lack of a significant reduction in the peak force and peak rate of force development after performing static stretching suggests that changes in muscle-tendon stiffness and a reduction in the quadriceps working length may not have occurred. Another possible explanation could be the greater amount of collagen and smaller number of elastin fibres in the muscle-tendon system of older adults (Magnusson et al., 1995); consequently, muscles and tendons become more rigid and less functional (Holland, Tanaka, Shigematsu, & Nakagaichi, 2002) and are therefore less affected by stretching (Handrakis et al., 2010).

We could not detect a significant effect of stretching on the iEMG activity of the vastus medialis, vastus lateralis and biceps femoris during peak force. Several neuromuscular responses to stretching concur with a reduction in neural activity, such as the autogenic inhibition promoted by the Golgi tendon organ, mechanoreceptors (type III afferents), and nociceptors (type IV afferents). These afferent mechanisms lead to a significant reduction in alpha motoneuron excitability. Some studies applying more extensive stretching protocols have investigated the mechanisms involved in the stretching-induced force deficit. Fowles et al. (2000) observed a significant decrease in the iEMG activity of the plantar flexor muscles after 30 min of static stretching, which returned to the initial conditions after 15 min. However, studies that applied a smaller stretching volume (10 to 20 min) did not observe changes in the iEMG activity of the plantar flexor muscles (Ryan et al., 2008). It is, therefore, feasible to assume that potential autogenic inhibition of muscle activation caused by Golgi tendon organ recipients or by type III and IV recipients would require an intense and prolonged stretching routine (Fowles et al., 2000). In the present study, the static stretching was interrupted upon the onset of pain and had a short duration. Discomfort and pain have not been reported during the peak force and peak rate of force development evaluation after stretching.

It is worth mentioning that in the present study only the quadriceps muscle was stretched. As agonist and antagonist muscle groups share the same pool of motoneurons, any change in agonist muscle activity could cause a decrease in antagonist muscle activity through a circuit-reflex (Crone, 1993). After static stretching (3 sets of 33 seconds each) of only the quadriceps muscle, McBride et al. (2007) observed a significant reduction in the iEMG activity of the biceps femoris without any changes in the iEMG activity of the vastus medialis and vastus lateralis. The stretching protocol may have caused alterations in different afferent feedback mechanisms, which could have changed the balance of agonist-antagonist muscle activity (McBride et al., 2007). A similar stretching protocol was used in the present study, and the iEMG activity of the biceps femoris remained unchanged under the stretching and control conditions during the peak force obtained in two different exercises. Hence, in older women, the balance of agonist-antagonist muscle activity may not be affected when only the quadriceps muscle is stretched.

An important factor to consider with regard to experimental design is the number of isometric contractions during the pre-experimental condition. The use of isometric contractions prior to stretching has been shown to potentially mask potential effects on the strength performance due to a decrease in the Achilles tendon stiffness (Kay & Blazevich, 2009). In this study, three maximal isometric contractions were performed prior to each condition, and we observed a decrease in the peak force and peak rate of force development values even under the control condition. Although Ryan et al. (2008) reported similar results, Gurjão et al. (2009) showed significant reductions in the peak force and peak rate of force development values of older women after stretching, even with the implementation of three maximal isometric contractions before the isometric test.

Finally, although our results have not shown any deleterious effects of stretching on muscle strength and activation in elderly women, it should be noted that only the isometric force production was assessed. A better understanding of this phenomenon in other types of muscle strength could have relevant implications for functional training design in older adults and warrants additional studies.

Conclusion

This study indicates that a small amount of stretching, performed as currently recommended for older subjects, does not influence the peak force, peak rate of force development and EMG activity in this population. A more extensive stretching protocol may still result in a negative influence on muscle force output, as supported by previous research. Thus, future research should investigate the possible dose-response between stretching and muscle force output in both single- and multiple-joint isometric exercises.

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