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Research article

Unilateral Plantar Flexors Static-Stretching Effects on Ipsilateral and Contralateral Jump Measures

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Abstract

The aim of this study was to evaluate the acute effects of unilateral ankle plantar flexors static-stretching (SS) on the passive range of movement (ROM) of the stretched limb, surface electromyography (sEMG) and single-leg bounce drop jump (SBDJ) performance measures of the ipsilateral stretched and contralateral non-stretched lower limbs. Seventeen young men (24 ± 5 years) performed SBDJ before and after (stretched limb: immediately post-stretch, 10 and 20 minutes and non-stretched limb: immediately post-stretch) unilateral ankle plantar flexor SS (6 sets of 45s/15s, 70-90% point of discomfort). SBDJ performance measures included jump height, impulse, time to reach peak force, contact time as well as the sEMG integral (IEMG) and pre-activation ($IEMG_{pre-activation}$) of the gastrocnemius lateralis. Ankle dorsiflexion passive ROM increased in the stretched limb after the SS (pre-test: 21 ± 4° and post-test: 26.5 ± 5°, $p < 0.001$). Post-stretching decreases were observed with peak force ($p = 0.029$), IEMG ($P<0.001$), and $IEMG_{pre-activation}$ ($p = 0.015$) in the stretched limb; as well as impulse ($p = 0.03$), and jump height ($p = 0.032$) in the non-stretched limb. In conclusion, SS effectively increased passive ankle ROM of the stretched limb, and transiently (less than 10 minutes) decreased muscle peak force and pre-activation. The decrease of jump height and impulse for the non-stretched limb suggests a SS-induced central nervous system inhibitory effect.

Key words: Athletic training; exercise performance; exercise training, crossover, cross-education.

Introduction

Several articles have reported non-local (e.g. upper versus lower body) or cross-over (contralateral muscle) effects with an exercised muscle affecting the performance of a non-exercised muscle when monitoring fatigue (Doix et al., 2013; Rattey et al., 2006; Regueme et al., 2007; Todd et al., 2003), and force/power (Carroll et al., 2006; Farthing et al., 2005; Lee and Carroll, 2007; Sariyildiz et al., 2011; Shima et al., 2002). However, few articles have examined the cross-over effect after static-stretching (SS) (Nelson et al., 2012). Both differences (Cramer et al., 2004) and lack of differences (Avela et al., 1999; Cramer et al., 2006; Guissard and Duchateau, 2004) have been observed between limbs for force and range of motion (ROM), however there are no articles related to cross-over effect with jumping tasks (power capacity). Cramer et al. (2004, 2006) exemplified this conflict with two studies that examined the effects of SS on isokinetic leg extension peak torque measures at two different velocities (2004 study: 60ºs^{-1} and 240ºs^{-1}, 2006 study: 60ºs^{-1} and 180ºs^{-1}) in the stretched and non-stretched limbs of men and women. The earlier study with men showed that peak torque decreased following the SS in both limbs and at both velocities while the latter study with women reported no contralateral effects. Marchetti et al. (2014) demonstrated the effect of upper body stretching on lower body performance. They employed 10 upper body stretches of 30s duration at 70-90% of the point of discomfort and found impairments of both the propulsion duration and peak force of a maximal concentric jump but no effect on lower limb muscle activation. Avela (1999) analyzed the effect of prolonged and repeated passive stretching of the triceps surae muscle on reflex sensitivity. The results demonstrated a decrease of muscle function immediately after the protocol, however the non-stretched leg (control leg) demonstrated nonsignificant changes in the maximal voluntary contraction (MVC). Nelson, et al. (2012) analyzed 10-week stretching program (4 times for 30s, with 30s rest, 3 d·wk^{-1}). The results indicated an increase in strength (1RM) for both legs (stretched and non-stretched limb), where the strength gain of the non-stretched leg was 56% of the stretched leg. Non-local muscle deficits and training adaptations suggest that SS-induced alterations are related to central nervous system mechanisms.

Several studies have reported deleterious effects of SS on different drop jump variables, such as jump height (Behm et al., 2001b; Behm and Chaouachi, 2011; Behm and Kibele, 2007; Rubini et al., 2007), contact time (Behm and Kibele, 2007; Rubini et al., 2007), and surface electromyography (sEMG) (Cornwell et al., 2002; Wallmann et al., 2005) with the stretched leg. These plyometric performance reductions can originate from neurophysiological (i.e. mechanoreceptors of the skin, muscle and joint proprioception), hormonal, cellular (structural changes such as titin), or mechanical (i.e. stiffness, torque-length characteristics) factors (Behm et al., 2001a; Behm and Chaouachi, 2011; Rubini et al., 2007), and in some studies, it might persist for over several hours post-stretch (Brandenburg et al., 2007; Fowles et al., 2000; Haddad et al., 2014; Power et al., 2004). Branden-

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burg et al. (2007) observed decreases immediately after SS on maximal height of the countermovement vertical jump, and it remained decreased during the 24 minute follow-up period. Power et al. (2004) demonstrated impairments of quadriceps force, and jump contact time from 1 to 120 minutes post-stretching. However, there are no studies that have examined the time course of SS effects on muscle pre-activation or time to peak force of the landing phase of the single-leg bounce drop jump (SBDJ). The landing phase is an important component of the jumping performance. Plyometric exercises that involve a rapid stretch-shortening cycle (SSC) involve both a pre-activation (muscle activation before landing to increase the joint stiffness) and pre-stretch of the muscles that incorporate muscle reflex activity and the storage and release of elastic energy (Cappa and Behm, 2013). It is also unknown whether any SS-induced deficits with the stretched leg would be transferred to the contralateral leg.

Therefore, the purpose of the present study was to evaluate the acute effects of unilateral ankle plantar flexors SS on (1) the sEMG (integral EMG {IEMG}, $IEMG_{pre\text{-}activation}$) and jump performance (jump height, total impulse, time to peak force, contact time) of non-stretched lower limbs during SBDJ tasks, and (2) time course and extent of sEMG (IEMG, $IEMG_{pre\text{-}activation}$), passive ROM and jump performance (jump height, total impulse, time to peak force, contact time) of the stretched lower limb with healthy adult males. It was hypothesized that both the stretched and non-stretched contralateral limbs would experience impairments.

Methods

Subjects

Based on a statistical power analysis derived from the IEMG data from Marchetti et al. (2014), fifteen subjects would be necessary to achieve an alpha level of 0.05 and a power (1-β) of 0.80. Therefore, 17 young, healthy, trained men (age: 24 ± 5 years, height: 1.74 ± 0.07 m, and weight: 77.3 ± 13.0 kg) were recruited to participate in this study. They had 3±1 years of experience with resistance training, at least 3 times a week, regularly. The participants in the study had no previous surgery on the lower extremities (specifically in the ankle joint); no history of injury with residual symptoms (pain, "giving-away" sensations) in the lower limbs within the last year. This study was approved by the research ethics committee of the University (Protocol #74/12).

Procedures

This was a quazi-experimental, repeated measures study. Prior to the data collection, subjects were asked to identify the preferred leg for kicking a ball, which was then considered the dominant leg. Of the 17 subjects, 15 were right-leg dominant. The experimental protocol consisted of (1) a brief submaximal jumping warm-up for 5 minutes; (2) a pre-stretching evaluation (passive ROM and three trials of maximal single-leg jumping task for each lower limb); (3) ankle plantar flexors SS protocol (only for dominant lower limb); (4) immediate post-stretching evaluation (passive ROM and three trials of maximal single-leg jumping task) for both lower limbs; and (5) further post-stretching evaluation at 10 and 20 minutes only for the stretched lower limb (three trials of unilateral jumping task), considering the mechanical stress imposed by the static- stretching protocol only on that particular limb. Only the pre-stretching evaluations were randomized between legs and subjects. The order of testing used in the pre-test was then maintained for the post-test, and all measures were performed at the same hour of the day, between 9 AM and 12 PM.

Maximal single-leg jumping task (Single-leg Bounce drop jump, SBDJ): The SBDJ was performed before and after the unilateral ankle plantar flexors stretching protocol (only the dominant lower limb was stretched). The SBDJ is a jump technique where the subject jumps maximally as soon as possible after landing. The technique emphasizes the ankle plantar flexors and involves minimum knee flexion and minimum ground contact time. Subjects were instructed to perform the SBDJ fall from a 15cm step, and terminate the landing phase in a standing position with their arms crossed on the chest. Immediately upon contact with the force plate (landing phase), subjects were instructed to jump maximally with minimal contact time. Subjects were allocated at least 1-minute rest between jumps. Vertical ground reaction forces (vGRF) and gastrocnemius lateralis (GL) surface electromyography (sEMG) were synchronized and analyzed to determine the effects of unilateral ankle plantar flexors stretching of each lower limb on SBDJ. Each subject performed three trials of SBDJ, however, for the data analysis, we considered the highest trial for pre-conditions and the first trial for all post-conditions. The first trial for post-conditions was considered in order to avoid the task-dependent effect (Enoka, 1995; Enoka, 2000), and consequently contaminating the stretching protocol effect.

Measures

Ankle Range of Motion (ROM): The subjects remained supine lying down with the lower limbs aligned and the ankle joint positioned at neutral position (90º to the ground). Then, a researcher passively moved the foot to the maximal ankle dorsiflexion ROM. The maximal passive ankle ROM was evaluated before and after the static-stretching protocol with a flexometer, with a sensitivity of 1º (Sanny®, Brazil).

Surface Electromyography (sEMG): The participants' skin was prepared before placement of the sEMG electrodes. Hair at the site of electrode placement was shaved and the skin was cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes 1-cm in diameter for each circular conductive area and 2-cm center-to-center spacing were placed bilaterally over the longitudinal axes of the GL in the direction of the line between the head of the fibula and the heel, according to Hermens et al. (2000). The sEMG signals of the GLs of both lower limbs were recorded by an electromyographic acquisition system (EMG system do Brasil, Brazil) with sampling rate of 2000 Hz using a commercially designed software program (DATAQ Instruments Hardware Manager, DATAQ Instruments, Inc., OH, USA). The sEMG activity was amplified (bi-polar differential amplifier, input impedance = 2MΩ, common mode rejection ratio >

100 dB min (60 Hz), gain x1000, noise based on resting signal> 5 µV), and analog-to-digitally converted (12 bit). A reference electrode was placed on the right clavicle.

Intervention

Unilateral ankle plantar flexor stretching protocol: During the SS protocol, all subjects remained supine lying down with the knee extended; the SS protocol consisted of a passive dorsiflexion stretch, of the dominant lower limb only. The researcher secured the ankle with one hand while applying force to the sole of the foot at the level of the metatarsal heads with the other hand using body weight to ensure sufficient force. The subjects performed six stretches of 45s, with 15s rest periods. Prior studies with similar and lesser durations and intensity of SS have impaired subsequent performance (Behm et al., 2001, 5x45s; Behm et al., 2004, 3x45s; Behm et al., 2006, 3x30s; Behm and Kibele, 2007, 4x30s; Power et al., 2004, 6x45s). The intensity was continually adjusted based on feedback from the subject to ensure the stretch subjectively achieved 70-90% of the point of discomfort (POD). Based on this same procedure used in prior investigations (Behm and Chaouachi, 2011; Behm and Kibele, 2007; Lima et al., 2014; Young et al., 2006), the subjects were informed that 0 = "no stretch discomfort at all" and 100% = "the maximum imaginable stretch discomfort". The SS protocol was applied and controlled (POD) by the same strength and conditioning researcher. During the resting periods, the subjects remained seated on a chair (10 and 20 minutes).

Data analysis

All of the force plate and sEMG data were analyzed with a customized Matlab routine (MathWorks Inc., USA).

SBDJ performance analysis: vGRF were collected from the force plate (EMG System do Brasil, São José dos Campos, Brazil) at a sampling frequency of 2000 Hz . The vGRF was filtered with a fouth-order 100-Hz low-pass zero-lag Butterworth filter, and normalized by the weight. Using the data of the SBDJ trial, we calculated the jump height, impulse, time to reach peak force and contact time. The jump height (cm) was calculated by using the velocity of the body center of mass at takeoff ($v_{takeoff}$) by using the following formula: $v_{takeoff}^2/(2g)$, where g is the acceleration of gravity, 9.8 m/s^2. To quantify the impulse (Kgf.s), the vGRF data was integrated during the entire contact time, and the time to reach the peak force was defined as the maximal value of vGRF data during the contact time (absorptive and propulsive phases). The contact time was defined as the sum of concentric and eccentric phases since there were no significant differences detected between the eccentric and concentric phases.

sEMG analysis: The digitized sEMG data were first band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For the muscle activation, we calculated the amplitude of the root mean square (RMS) (150ms moving window) of the sEMG, and then the RMS was integrated (IEMG) during the entire contact time of the SBDJ. For the muscular pre-activation, the IEMG data was calculated 50ms before the beginning of the vGRF ($IEMG_{pre-activation}$). All dependent variables were normalized by the pre-stretching condition.

Statistical analyses

The normality and homogeneity of variances within the data were confirmed with the Shapiro-Wilk and Levene tests, respectively. To ensure the effectiveness of the SS protocol, we used a paired t-test before and after the SS protocol. To test whether the SS protocol resulted in SBDJ jump performance (jump height, total impulse, time to peak force, contact time) and muscle activity differences (IEMG, $IEMG_{pre-activation}$), a repeated-measure ANOVA (2x2) was used, with factors being the lower limb (stretched and non-stretched) and conditions (pre-stretching and immediately post-stretching). Another one-way ANOVA was completed to test whether prolonged changes in all variables continued over time (pre, immediately post, and after 10 and 20 minutes of the SS protocol) for the stretched limb only. Post-hoc comparisons were performed with the Bonferroni test. Cohen's formula for effect size (ES) was calculated, and the results were based on the following criteria: <0.35 trivial effect; 0.35-0.80 small effect; 0.80-1.50 moderate effect; and >1.5 large effect, for recreationally trained according to Rhea (2004). Test-retest reliability of the two pre-tests was calculated with intraclass correlation coefficients (ICC) and absolute (SEM) reliability according to Shrout and Fleiss (1979). ICC (SEM) values of maximum jump height for both lower limbs (stretched and non-stretched limb) on pre-stretching protocol were 0.91 (0.85) and 0.97 (0.94), respectively and for immediately post-stretching protocol were 0.95 (0.87) and 0.98 (0.95), respectively. An alpha of 5% was used for all statistical tests.

Results

The passive ROM of the stretched lower limb increased significantly from before to after the SS protocol (mean ± SD: pre-test: 21 ± 4° and post-test: 26.5 ± 5°, $p < 0.001$, ES = 1.26, Δ% = 19.2%).

There were decreases in time to peak force between pre-stretching and immediately post-stretching of the stretched lower limb (P=0.029, ES=2.85, Δ%=27.8%, Figure 1a). There were no significant differences in contact time between pre- and post-stretching for both lower limbs (Figure 1b). There were also no significant differences in the eccentric and concentric phases of the contact period. Additionally, there were decreases for impulse ($p = 0.03$, ES = 0.29, Δ% = 5.7%, Figure 1c) and jump height ($p = 0.032$, ES = 0.67, Δ% = 9.5%, Figure 1d) between pre-stretching and immediately post-stretching only for the non-stretched lower limb.

There were no significant differences in all variables (peak force, contact time and impulse) after 10 and 20 minutes after the stretching protocol ($p > 0.05$).

There were decreases in the IEMG between pre-stretching and immediately post-stretching only for stretched lower limb ($p < 0.001$, ES = 1.5, Δ% = 14%), and between stretched and non-stretched lower limb ($p < 0.001$, ES = 0.7, Δ% = 15.6%). There were decreases in the IEMG between pre- and all post-stretching protocols

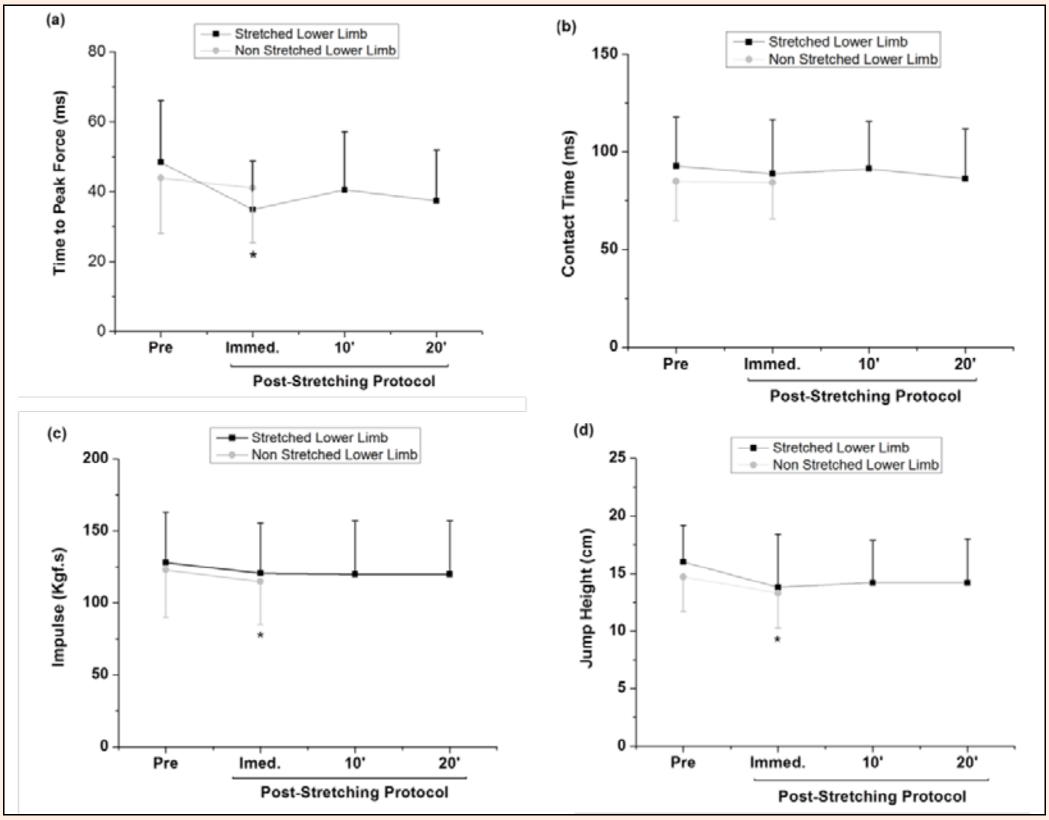

Figure 1. Mean and standard deviation of the vGRF variables (a) time of peak force; (b) contact time; (c) jump height and (d) impulse, before and after static- stretching protocol for stretched and non- stretched lower limbs. *Significant difference between pre and post-stretching protocol, $p < 0.05$.

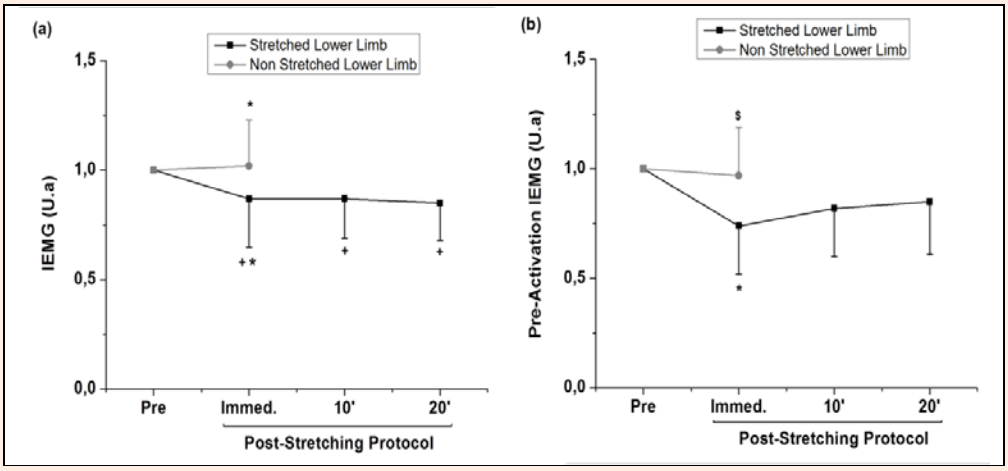

Figure 2. Mean and standard deviation of the (a) IEMG and (b) $IEMG_{pre\text{-}activation}$ of gastrocnemius lateralis before and after static- stretching protocol for stretched and non- stretched lower limbs. *Significant difference between pre and post-stretching protocol, $p < 0.05$; +Significant differences between pre and post-stretching protocol, $p < 0.05$. $Significant differences between lower limbs, $p < 0.05$.

(immediate: $p < 0.001$; 10': $p < 0.001$; and 20': $p < 0.001$) (Figure 2a).

There were decreases in the $IEMG_{pre\text{-}activation}$ between pre-stretching and immediately post-stretching only for stretched lower limb ($p = 0.001$, $ES = 1.4$, $\Delta\% = 26\%$). There was decrease in $IEMG_{pre\text{-}activation}$ between limbs for immediately post-stretching condition, with stretched lower limb presenting lower values ($p = 0.001$, $ES = 1.05$, $\Delta\% = 23.7\%$). There were no significant differences in the $IEMG_{pre\text{-}activation}$ between pre and post-stretching protocol after 10 and 20 minutes ($p > 0.05$) (Figure 2b).

Discussion

The main findings of the present study were the significant increase in passive ROM and decrease of both the time to peak force, IEMG, and the IEMGpre-activation for the stretched lower limb. However, these changes, of the stretched lower limb, were no longer significantly different after 10 minutes of recovery, with the exception of the IEMG. Secondly, the non-stretched lower limb after the contralateral SS protocol presented a significant decrease in impulse and jump height when compared to pre-stretching.

The acute effects of unilateral ankle plantar flexors SS (270s at 70-90% POD) significantly increased ankle dorsiflexion passive ROM of the stretched limb by 19.2%. Previous studies have showed decreases in power production following passive static- stretching by using durations above 90s (Robbins and Scheuermann, 2008). A significant SS-induced jump performance reduction was observed only for the time to reach peak force and GL pre-activation. These results might represent a reduction of both the landing and propulsion phase of the SBDJ. The reduction of time to reach peak force results in an abbreviated time to absorb the landing's impact, and consequently, the mechanical stress would be higher. In addition, a smaller pre-activation of the GL also might provide less active ankle joint stiffness, against the external load imposed by the landing phase, and these SS-induced results might be related to changes in both peripheral neural (proprioception) and mechanical output (musculotendinous unit or stiffness) by affecting the ability to produce force rapidly. However the limitations of the present study did not permit an identification of the specific locale of the alterations.

The lack of SS-induced impairments 10 minutes following SS is an important finding. Although many studies report SS-induced performance deficits (see reviews: Behm and Chaouachi 2011; Kay and Blazevich 2012), the post-stretch testing may not coincide with typical warm-up to competition timelines (~5-15 min). With many sports, the warm-up precedes a return to the dressing room where strategies, final equipment adjustments and other pre-match preparations are completed. Additionally, the return time to the field, court, or ice, meeting with the officials and other activities can result in a duration between the warm-up and the competition of 10-15 minutes. Hence the SS-induced impairments prior to 10-20 minutes post-warm-up may not impact competition performance.

Considering the cross-over effect on the non-stretched lower limb, previous studies have suggested that SS may affect the concentric torque and sEMG (Cramer and Housh, 2005), but not eccentric peak torque (Cramer et al., 2006). Avela et al., (1999) reported minimal effects of stretching on the non-stretched limb after stretching the contralateral limb (plantar flexors). In the present study, significant contralateral SS-induced decreases in power-related variables such as impulse and jump height of the non-stretched lower limb, were observed. The lower values for these power variables may arise from the global effects of afferent input or central (spinal and supraspinal levels) factors (Trajano et al., 2013), since there was no mechanical stretching of this limb, however, the rationale for a lack of SS-induced jump deficits in the stretched limb is not clear. As the EMG-force relationship has been described as curvilinear (Behm and Sale, 1996), the IEMG$_{preactivation}$ deficit would not directly correlate with any changes in force or power. Furthermore, Magnusson et al. (2000) reported that a greater extent of flexibility provided an apparent greater tolerance to an externally applied load and larger change in moment arm, which might compensate for neural derived deficits.

The effects of prolonged and intense SS on the joint receptors might lead to inhibitory effects on motoneurons, such as autogenic inhibition and Type III (mechanoreceptor) and IV (nociceptor) afferents and Golgi tendon organ discharge, and their greatest effects can remain for 5-10 minutes (Behm and Kibele, 2007). As the SS was conducted at 70-90% of the point of discomfort, the muscular pain can adversely affect muscular force through central mechanisms that can affect both local and generalized (non-local) responses (Graven-Nielsen et al., 2002). These findings support the present results since SS protocol affected muscle activation (GL activity) only immediately after the experimental protocol. However, Fowles et al. (2000) showed a reduction in force and sEMG after SS, as well as recovery to the initial values over time (30 minutes). This may be due to their extensive stretching duration (135s of 13 stretches over 33 min). Brandenburg et al. (2007) observed an immediate decrease of the jump height after SS on countermovement vertical jump, and it remained decreased during the 24 minutes follow-up period. Power et al. (Power et al., 2004) demonstrated that these deficits occur 1 minute post-SS and can continue for 120 minutes post-stretching, for the quadriceps force, and contact time. These observed differences might be related to mechanical differences among jumping tasks. For example, during this study, the bounce drop jump was analyzed, which has a lower contact time and time to produce force, thereby producing higher stress on the ankle joint.

We recognize that this study has some limitations. The placement of the sEMG electrodes over the GL might have led to cross-talk from adjacent muscles, such as the soleus, and peroneal muscles. However these muscles all contribute to plantar flexion. The feet touching on the floor during the resting period might affect the static dorsiflexion stretching effect. Although the SBDJ was used to emphasize plantar flexion contractions and minimize knee and hip joint contributions and variability, there was the possibility of minor changes in jump kinematics. We chose to use the most progressive SS protocol in the literature that included subjective information about the stretching intensity (Behm and Chaouachi, 2011). However, we do recognize that the intensity of the stretching might not be commonly utilized during warm-ups to activity or during the rehabilitation processes. In addition, we can relate the high variability of the data (sEMG) with the inter-subject differences of the SS protocol intensity. We also used a healthy, non-athletic population, and our results are not generalizable to other conditions, populations, and diseases.

Conclusion

In conclusion, the SS protocol effectively increased passive ankle ROM of the stretched limb. The increased

ROM appears to decrease the muscle peak force and pre-activation; however these finding were only a temporary effect (less than 10 minutes after the SS protocol was applied). The decrease of jump height and impulse for the non-stretched limb suggests a central nervous system inhibitory mechanism from SS. Whether the increased ankle ROM and subsequent decrease in power, and muscle activity influence the risk of ankle injury and instability remains unknown.

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Key points

- When considering whether or not to SS prior to athletic activities, one must consider the potential positive effects of increased ankle dorsiflexion motion with the potential deleterious effects of power and muscle activity during a simple jumping task or as part of the rehabilitation process.
- Since decreased jump performance measures can persist for 10 minutes in the stretched leg, the timing of SS prior to performance must be taken into consideration.
- Athletes, fitness enthusiasts and therapists should also keep in mind that SS one limb has generalized effects upon contralateral limbs as well.

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