Acute Effects of Unilateral Self-Administered Static Stretching on Contralateral Limb Performance

David G. Behm, Rebecca J. Lau, Justine J. O’Leary, Machel C.P. Rayner, Elizabeth A. Burton, and Laura Lavers

Background: Prolonged static stretching (SS) has been shown to impair subsequent performance of a stretched muscle. There is evidence that unilateral SS can have crossover or global effects on range of motion (ROM), but there is scant information regarding whether prolonged SS also impairs the performance of contralateral muscle groups.

Purpose: The objective of this study is to investigate the effects of self-administered unilateral SS with a TheraBand® stretch strap on contralateral hip flexion ROM and knee extension isometric maximum voluntary contraction (MVC) force and muscle activation.

Study Design: This study used an experimental repeated-measures intervention design.

Methods: In total, 14 male participants performed self-administered SS of the dominant quadriceps and hamstrings (eight repetitions of 30 s each) with a TheraBand stretch strap. The aim was to observe pre- to post-SS-induced changes in hip flexion (hamstrings) ROM, knee extension (quadriceps) isometric force, and muscle activation (as recorded with electromyography [EMG]) in both dominant (experimental limb) and non-dominant lower limbs (control lower limb).

Results: A significant tested leg x time interaction \( F(1,13) = 6.58; P = 0.04; \eta^2 = 0.210 \) demonstrated that the ROM increases in both the stretched and contralateral nonstretched legs by 6.7% \((d = 0.53)\) and 4.3% \((d = 0.38)\), respectively. There were no significant interactions for MVC force or muscle activation for either leg.

Conclusion: The lack of crossover MVC changes suggests that the mechanism for contralateral increases in ROM may be stretch tolerance.

Clinical Relevance: Individuals who are injured or are undergoing rehabilitation should continue to stretch the noninjured limb to maintain or improve flexibility of the injured limb.

Keywords: Cross education; range of motion; strength

Key Points: Unilateral SS can increase ROM in both the stretched and contra-lateral limb; this cross-over effect is thought to result from increased tolerance to stretch.

Static stretching (SS) is used extensively to increase range of motion (ROM) around a joint.\(^1\,\text{-}^3\) Comprehensive reviews and original research have documented that prolonged SS (i.e. >60 s per muscle group)\(^1\,\text{-}^3\) performed in isolation (no prior aerobic activity or subsequent dynamic activity)\(^1\,\text{-}^4\,\text{,}^5\) can impair subsequent performance (i.e. force, power, velocity, balance).\(^6\,\text{-}^10\)

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The mechanisms underlying these SS-induced deficits have been attributed to both peripheral (musculotendinous) and central (neural) components. Peripheral components can include SS-induced decreases in tendon stiffness that can adversely affect electromechanical coupling \(^1\) and force–length relationships.\(^1\) However, Kay and Blazevich\(^1\) contend that changes in the force–length relations are unlikely mechanisms, as they found impairments with no change in the length of the gastrocnemius. A second proposed mechanism is related to SS-induced contractile fatigue or damage,\(^1\) as evidenced by decrements in evoked twitch forces that may signify damage to the excitation–contraction coupling process or contractile elements.\(^7,13\) Furthermore, the tension associated with SS can impede blood flow and oxygen to tissues, resulting in accumulation of metabolites, reactive oxygen species, and reactive nitrogen species.\(^1,14\)

In addition to peripheral components of fatigue, central neural factors can also play a role. Whereas a number of studies document SS-induced depression in electromyography (EMG) activity\(^1,2,7,9\) and Hoffman (H)-reflex (afferent excitability of the motoneuron),\(^15\) other studies report no change in EMG activity following SS.\(^1,16,17\) Although these changes occur within the stretched muscle groups, there is evidence that SS induces central or global effects by increasing ROM in nonstretched muscles. Nonlocal muscle effects have been reported when unilaterally stretching the quadriceps and observing ROM increases in the contralateral quadriceps (“crossover effect”).\(^18\) Behm et al.\(^19\) showed that stretching the hip adductors can increase horizontal shoulder abduction ROM, while stretching the shoulders improved the ROM of the hamstrings (nonlocal, global effects). The aforementioned SS-induced performance impairments might also show crossover effects.

Following a 10-week stretching program, Nelson et al.\(^20\) found that strength increases in the contralateral untrained muscle. Lima et al.\(^21\) examined the acute effects of SS of unilateral plantar flexors by means of EMG during balance measures, and reported no change in the performance of contralateral muscles. Similarly, Chaouachi et al.\(^18\) did not find any SS- or dynamic stretch-induced changes in contralateral homologous (quadriceps) isokinetic torque or power. In contrast, Marchetti et al.\(^22\) reported increased lower body propulsion time (not favorable for performance) and decreased force after SS of the muscles of the upper body. Another study from the same laboratory\(^23\) showed that six sets of SS of the shoulder muscles for 45 s per set decreased the EMG activity of auxiliary muscles such as pectoralis major and triceps brachii. With few studies examining the crossover effects of stretching and with the conflict present in the literature regarding whether SS-induced strength impairments can also induce crossover effects, further investigations are necessary. Furthermore, in the aforementioned studies, researchers applied stretch to the individuals’ muscles, which may have inadvertently placed excessive tension on musculotendinous units. It is unknown whether self-administered stretching techniques with a stretch strap would have similar or dissimilar crossover effects.

Hence, the objective of this study was to examine the effect of acute self-administered SS (with a TheraBand\(^6\) [Performance Health, Akron, OH] stretch strap) on contralateral limb ROM and isometric strength and EMG readings. Such a research could have implications for performance and rehabilitation when using unilateral SS and possible contralateral or crossover effects.

**METHODS**

**Participants**

A statistical power analysis of related studies\(^18,19\) revealed that 12–14 participants would be required to achieve an α value of \(P < 0.05\) with a power of 0.8. Hence, a convenience sampling of 14 physically active men (19–30 years) volunteered to participate (Table 1). “Physically active” was defined as an individual participating in 30–60 min of moderate-to-vigorous activity per day. Participants were requested to maintain their current physical activity levels and to refrain from consuming caffeine and alcohol before testing (24 h before the test). Each subject completed the following documents: PAR-Q (Physical Activity Readiness Questionnaire; to assess the health status of the participant), the Healthy Physical Activity Participation Questionnaire (to assess participants’ physical activity levels)\(^24,25\) and an informed consent form. Ethical approval was granted by the institution’s Interdisciplinary Committee on Ethics in Human Research.

**Experimental Design**

Each session commenced with a 5-min warm-up on a Monark\(^8\) Ergomedic 828E cycle ergometer (Monark Exercise AB, Vansbro Sweden) TheraBand stretch strap (Performance Health Inc., Akron, Ohio, USA) at 70 RPM with 1 kilopond resistance. Self-administered SS of the dominant quadriceps and hamstrings (eight repetitions of 30 s each) with a TheraBand stretch strap was used to observe possible pre- to post-SS-induced changes in hip flexion (hamstrings) ROM, knee extension (quadriceps) isometric force, and muscle activation (as recorded on electromyography [EMG]) in both the dominant (experimental limb) and nondominant lower limbs (control lower limb). The dominant lower limb of each participant was defined as the one they used to kick a soccer ball. During testing, the order of nondominant and dominant limb...
measurements was randomized using a random number generator system. Before and after stretching, subjects completed three trials of the following measures: hip flexion (hamstrings) ROM, knee extension (quadriceps) isometric maximum voluntary contraction (MVC), and rectus femoris activation (EMG) during MVC.

**Pre- and Post-Intervention Measures**

**MVC Force.** To perform knee extension MVCs, sat on a specially designed bench with their knee in 90° of flexion; their knee and thighs were fixed in position using two straps and the upper body was supported by a backrest. The foot was inserted into a padded cuff, which was attached to the high-tension wire and the Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, ON, Canada) with the knee and ankle joints flexed at a 90° angle. The warm-up for the pretest MVC assessment consisted of four MVCs at ~50% of the individual’s perceived MVC and of one MVC at ~90% of their perceived MVC. Pretest MVCs were performed twice for both the dominant and nondominant lower limbs with a 3-min recovery period between MVCs. A third contraction was performed if the second reading was 5% greater than the initial two contractions’ readings. Posttest MVCs involved two contractions. Forces were detected by the strain gauge, amplified (Biopac Systems Inc. DA 100 and analog-to-digital converter MP100WSW; Holliston, MA), sampled at 2000 Hz, and stored on a computer. The highest peak force of the two to three MVCs was used for analysis. Analysis was conducted with the AcqKnowledge software system (AcqKnowledge III, BIOPAC Systems Inc.). Prior studies from this laboratory have reported excellent reliability for these measures.26,27

**Hip Flexion.** The participant was asked to lie in a supine position next to a wall protractor. With an extended knee (straight leg), the same researcher for all stretch testing passively flexed the hip till the point of maximum discomfort was reached. Three ROM measurements were recorded for both the pre- and posttests for the dominant and nondominant legs. There was a 10-s rest period between each passive stretch. Prior studies from this laboratory have reported excellent reliability for these measures.6,7,9,29

**Static Stretching Intervention.** The SS intervention included 8 min of SS of hamstrings and quadriceps. The participant was instructed to lie relaxed in a supine position on a testing table to perform passive stretching of hamstrings. The participant placed their foot into a loop within the TheraBand stretch strap, and then by pulling on the strap, performed dominant hip flexion till maximal discomfort (stretch tolerance) was experienced. The stretch was then held for 30 s. The participant would then rotate over to the prone position (~5-s transition period). The participants grasped their dominant ankle with their ipsilateral hand and flexed their knee to the point of maximal discomfort (stretch tolerance) for 30 s. This sequence was repeated eight times.

After the stretching intervention, there was a 1-minute transition period to relocate for testing. Posttests followed the same procedure as previously described.

**Control Session**

The control session was conducted in the same manner as the experimental session, excluding the stretching intervention. During this session, the participant was instructed to lie on the table in a supine position

| Table 1. Reliability: intraclass correlation coefficients |
|---------------------------------|-----------------|-----------------|
|                                 | Hip Flexion Range of Motion | Knee Extension MVC Force | Rectus Femoris RMS EMG Activity |
| Dominant Leg                   | 0.907            | 0.926           | 0.838                           |
| Nondominant leg                | 0.877            | 0.935           | 0.741                           |

cells abraded and the area cleaned with isopropyl alcohol. The interelectrode spacing was 10 mm. All the EMG signals were collected using the Biopac data acquisition system (AcqKnowledge III, Biopac System Inc., Holliston, MA) at a sample rate of 2000 Hz (impedance = 2 MΩ; common mode rejection ratio >110 dB min (50/60 Hz); noise >5 μV). The signal was smoothed (averaged over every 10 samples) and a bandpass filter (10–500 Hz) was applied before digital conversion. Prior studies from this laboratory have reported excellent reliability for these measures.26,28

**Rectus Femoris Activation.** The mean amplitude of the root mean square (RMS) EMG activity was collected 500 ms before and 500 ms following the attainment of peak force during dominant knee extensors’ MVC. Surface EMG electrodes (Kendall® Medi-trace 133 series, Ag/AgCl, Chicopee, MA) were placed superficially on the midpoint of the muscle belly (midway between the iliac crest and the patella head) for the rectus femoris. The skin on which electrodes had to be placed was lightly shaved, dead epithelial cells abraded and the area cleaned with isopropyl alcohol. The interelectrode spacing was 10 mm. All the EMG signals were collected using the Biopac data acquisition system (AcqKnowledge III, Biopac System Inc., Holliston, MA) at a sample rate of 2000 Hz (impedance = 2 MΩ; common mode rejection ratio >110 dB min (50/60 Hz); noise >5 μV). The signal was smoothed (averaged over every 10 samples) and a bandpass filter (10–500 Hz) was applied before digital conversion. Prior studies from this laboratory have reported excellent reliability for these measures.26,28

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for 30 s and then rotated to prone position for 30 s with 5-s rest between rotations; this sequence was repeated eight times.

**Statistical Analysis**

First, normality (Kolmogorov–Smirnov) and homogeneity of variances (Levene) tests were conducted for all dependent variables. If the assumption of sphericity was violated, the Greenhouse–Geisser correction was used. Data were analyzed using a three-way ANOVA repeated-measures design. The factors included in the ANOVA were tested limb (stretched versus nonstretched leg), condition (SS versus control), and testing (pre- versus posttest). An α value of $P < 0.05$ was considered statistically significant. Effect sizes ($t = \text{mean change/standard deviation of the sample scores}$) were also calculated and reported.

Descriptive statistics and figures include means ± standard deviation (SD).

**RESULTS**

All reliability measures were excellent ($r = 0.84–0.93$) with the exception of good reliability ($r = 0.74$) for the rectus femoris RMS EMG activity. Intraclass correlation coefficients are reported in Table 1.

**Range of Motion**

A significant main effect for time [$F_{(1,13)} = 18.47; P = 0.001; \eta^2 = 0.587$] indicated that ROM increased 3.4% overall. A significant condition × time interaction [$F_{(1,13)} = 6.0; P = 0.029; \eta^2 = 0.316$] illustrated that the stretch condition significantly improved ROM by 5.1% (d = 0.74) compared to the control condition that gave trivial ROM improvement of 1.8% (d = 0.15). A significant tested leg × time interaction [$F_{(1,13)} = 6.58; P = 0.04; \eta^2 = 0.210$] showed that both the stretched and contralateral nonstretched lower limbs saw increased ROM by 6.7% (d = 0.53) and 4.3% (d = 0.38), respectively. The increase in ROM in the stretched leg was nearly significantly ($P = 0.056; d = 0.12; 2.5%$) greater, by a small magnitude, than that in the nonstretched leg (Figure 1).

**Maximal Voluntary Contraction Force**

A significant main effect for tested leg [$F_{(1,13)} = 7.31; P = 0.018; \eta^2 = 0.360$] showed that the dominant, stretched leg exerted 7.1% (d = 0.24), greater force than the nondominant, nonstretched leg. A significant main effect for time [$F_{(1,13)} = 15.32; P = 0.002; \eta^2 = 0.541$] showed a 7.7% (d = 0.26) pre- to posttest MVC force decrease.

**Quadriceps Electromyography Activity.** A significant main effect for time [$F_{(1,13)} = 31.34; P < 0.0001; \eta^2 = 0.707$] displayed a 16.5% (d = 0.37) decrease in rectus femoris EMG activity with conditions combined.

**DISCUSSION**

The most important finding of this study was the crossover stretching effect with increases in hip flexion ROM for both the stretched leg and contralateral, homologous muscle, nonstretched leg. Second, there were no significant adverse effects upon MVC force or EMG activity for the stretched or contralateral nonstretched leg.

Crossover (contralateral homologous muscles), and global (full body), or nonlocal muscle effects are ubiquitous in the literature with evidence of fatigue and potentiation in nonexercised muscles. The crossover stretching effect in the present study is in accordance with Behm et al. who found global stretching effects in which stretching the hip adductors (gracilis, obturator externus, adductor brevis, adductor longus, and adductor magnus) improved shoulder horizontal abduction ROM, while stretching the shoulder muscles increased hip flexion ROM. The present study was partially in accordance with Chaouachi et al. who showed near-significant and significant increases in crossover hip flexion ROM with SS and dynamic stretching, respectively. They found nonsignificant, but of a large magnitude, ROM improvements for SS with 5.6% (P = 0.07; d = 1.01) and 4.2% (P = 0.17; d = 0.85) improvements from pretest to 1- and 10-min posttest, respectively. The present study showed a significant, but of a small magnitude (d = 0.38), and relatively similar contralateral ROM increase of 4.3%. The Chaouachi et al. and the present study had a similar volume of stretching; however in the former study, the participants were highly trained national-class rowers who were tested for isokinetic torque and power at 60°.s⁻¹ and 300°.s⁻¹, respectively. Hence, although the crossover ROM results were not precisely similar (significant versus near-significant; small versus large magnitude), the results of these two studies in conjunction with the global ROM improvements in the Behm et al. study provide strong evidence for nonlocal muscle or crossover stretching effects.

The lack of significant adverse crossover effects upon MVC force and muscle activation is also in accordance with Chaouachi et al. With the same volume of stretching, there were no significant decrements in isokinetic torque and power at 60°.s⁻¹ and 300°.s⁻¹, respectively, or isometric force and muscle activation in the present study. Other crossover or nonlocal muscle response results may lend some insight into the mechanisms underlying the nonlocal or crossover stretching effect. For example, following unilateral fatigue protocols,
the nonexercised limb showed fatigue or deficits in MVC force with decreased spinal and supraspinal excitability. Similar to SS, unilateral rolling can improve the ROM of the rolled and contralateral muscle groups, as well as increase contralateral pain pressure threshold (increased pain tolerance). Improved rolling-induced crossover ROM and pain tolerance have also been attributed to neural modulation. For example, unilateral rolling of the quadriceps showed decreased afferent excitability of the contralateral spinal motoneuron (Hoffman H-reflex). SS-induced impairments in force have also been attributed to neural inhibition or disfacilitation. The lack of MVC force and EMG decrements would suggest that there was no substantial neural system depression, and thus, increases in crossover ROM would not primarily be because of changes in neural responses. It is also highly unlikely that the contralateral nonstretched limb would experience an increase in ROM owing to mechanical changes such as musculotendinous compliance or stiffness. Therefore, if it is unlikely that neural or mechanical mechanisms are at play, then the increased crossover ROM may be attributed to a psychophysiological mechanism.

Magnusson has attributed acute increases in flexibility to an increase in stretch tolerance. Although the mechanisms underlying improved stretch tolerance are not clear, it would involve a somatosensory perception of musculotendinous tissue length and tension changes and hence must involve cortical activity. Two foam rolling studies showed increases in pain pressure thresholds in the contralateral limbs, which suggests a global pain modulatory system. The extensive cortical connectivity would suggest that increased stretch or pain tolerance would have global body ramifications. Hence, we hypothesize that unilateral SS promoted an increase in stretch tolerance, which had crossover or global consequences, resulting in an increased crossover/contralateral ROM.

The lack of MVC force and muscle activation impairments contradicts many SS studies in the literature, which report performance impairments following prolonged SS. However, all these SS protocols had the researcher move the limb through and to the maximum tolerable ROM. In the present study, participants controlled their own ROM with a TheraBand stretch strap. Although in the aforementioned studies and the present study, the participants were asked to go to the maximum point of discomfort (stretch tolerance), a researcher would not have the essential feedback from the proprioceptive and pain detection systems of an individual whose limbs have been stretched to assess the force or torque applied to the limb. Hence, it may be possible that some of the reported SS-induced performance impairments in the literature might be attributed to excessive forces placed upon a stretched or elongated muscle, leading to musculotendinous damage, whereas a self-administered stretch would be more sensitive to the possibility of excessive applied forces.

A limitation of this study is the inclusion of only young adult, male participants. The lack of a diverse sample limits the findings application to both sexes and possible changes over a life span.

**CONCLUSION**

In summary, eight repetitions of 30 s of self-administered SS of the quadriceps and hamstrings had positive effects on contralateral hip flexion ROM with no impairments of MVC force or muscle activation. The
most likely mechanism for the increased crossover ROM was increased stretch (pain) tolerance.

**CLINICAL RELEVANCE**

The results of the present study can be used by individuals who are either injured or are undergoing rehabilitation and thus should continue to stretch the noninjured limb to maintain or improve the flexibility of the injured limb.

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