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Research article

The Effects of Static Stretching 2-Hours Prior to a Traditional Warm-Up on Performance

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Abstract

Whereas prolonged static stretching (SS: >60-seconds per muscle) can increase range of motion (ROM) for up to 2-hours, it can also decrease maximal voluntary isometric contraction (MVIC) forces, countermovement (CMJ) and drop jump (DJ) heights, and muscle activation immediately after the stretching exercise. When an appropriate SS duration (<60-seconds per muscle) is incorporated into a dynamic warm-up, performance decrements are often trivial. However, there is a lack of studies that observed the effects of extensive SS (180-seconds) 2-hours prior to a dynamic warm-up. The objective was to investigate ROM and performance effects of prolonged SS, 2-hours prior to a traditional warm-up. This study investigated 9 female and 8 male healthy recreationally active, young adult participants on the effects of prolonged SS (180-seconds per muscle) of the quadriceps and hamstrings, 2-hours before a traditional warm-up compared to an active control condition on hip flexion ROM, knee extension and flexion MVIC forces, CMJ, DJ, and quadriceps and hamstrings electromyography (EMG). There were no significant changes in knee flexion/extension MVIC forces, EMG, CMJ, or DJ height. However, there was significant, small magnitude ($p = 0.002$) greater post-warm-up left hip flexion ROM (115.4° ± 17.2) than pre-SS (108.9° ± 17.13, Effect size [ES]: 0.28) and control post-warm-up ($p = 0.05$, ES: 0.31, 109.5° ± 20.55). Similarly, right hip flexion ROM (117.2° ± 16.5) also demonstrated significant small magnitude ($p = 0.003$) greater than the pre-SS (112.4° ± 18.4, ES: 0.22) and control post-warm-up ($p = 0.046$, ES: 0.33, 110.8° ± 20.5). Additionally, significant, large magnitude greater hip flexion ROM was observed with the women vs. men (ES: 1.29 – 1.34). Significant hip flexion ROM increases were not accompanied by significant changes in knee flexion/extension MVIC forces, EMG, or jump heights, suggesting that extensive SS can positively impact ROM without performance deficits when followed by a traditional warm-up, 2-hours after SS.

Key words: Range of motion; electromyography; jump; maximal voluntary isometric contraction; strength.

Introduction

Stretching has long been an important aspect of preparing for physical activity to improve range of motion (ROM) (Behm, 2024; Behm et al., 2015; 2022; Konrad et al., 2024; Lima, 2019; Marchetti et al., 2022; Murphy et al., 2010) and reduce muscle (Takeuchi et al., 2024) or musculotendinous injury risk (Behm et al., 2015; 2021b; 2023a). There is conflict in the literature regrading whether longer durations and higher intensities of static stretching (SS) either promote greater ROM (Behm, 2024; Marchetti et al., 2022) or have no greater significant effect (Behm, 2024; Behm et al., 2015; Konrad et al., 2024). However, an acute session of prolonged SS (> 60 seconds per muscle group) has been shown to induce performance (e.g., muscle activation, strength, power, jump height, sprint speed, reaction and movement time) impairments while dynamic stretching can improve performance or not induce impairments (Behm, 2024; Behm and Chaouachi, 2011; Behm et al., 2015; 2021d; Chaabene et al., 2019; Kay and Blazevich, 2012; Lima et al., 2019). However, certain sports require specific or more extensive flexibility requirements (e.g., gymnastics, figure skating, martial arts) compelling athletes to engage in high intensity and prolonged SS prior to competition or practice (Behm, 2024; Marchetti et al., 2022) but such stretching prescriptions may also induce performance decrements (Marchetti et al., 2022).

Enhancement of ROM as well as performance deficits associated with prolonged SS in isolation (i.e., no additional dynamic activities) have been reported to persist for up to 1-2 hours post-stretching (Fowles et al., 2000, Power et al. 2004) with performance deficits sustained even 24 hours in one study (Haddad et al., 2013). However, when an appropriate duration of SS is incorporated into a full dynamic warm-up routine, the degree of impairment is typically classified as trivial (Behm and Chaouachi, 2011; Behm et al., 2015; 2021d; Blazevich et al., 2018; Chaabene et al., 2019; Kay and Blazevich, 2012; Murphy et al., 2010; Samson et al., 2012). For example, although moderate durations of SS (30 and 60-s) within a dynamic warm-up demonstrated trivial performance deficits, prolonged SS of 120-s within a full dynamic warm-up still induced performance impairments. While the more prolonged 120-s of SS provided the greatest ROM (vs. 30 and 60-s) increases, it also impaired maximum voluntary isometric force, muscle activation (electromyography) and instantaneous strength (force produced in the first 100 ms) (Reid et al., 2018).

The mechanisms of prolonged SS effects on performance have been attributed to disfacilitation of afferent muscle spindle reflex activity, suppression of persistent inward currents (PICs: facilitation of ionic channels amplifying the gain of the spinal motoneurons), decreased voluntary activation, subsequent increases in perceived effort and morphological changes such as decreased muscle stiffness (Behm, 2024; Behm et al., 2015; 2021d). In contrast, the dynamic stretching component of a warm-up would tend to further excite corticospinal and muscle spindle reflex excitability as well as thixotropic effects on tissue viscosity reducing the resistance to movement (Behm 2024; Behm et al. 2015; 2021d).

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The common recommendation to not SS for prolonged periods (>60-s per muscle group) during a warm-up (Behm, 2024; Behm and Chaouachi, 2011; Behm et al., 2015; 2021d; Chaabene et al., 2019; Kay and Blazevich, 2012; Lima et al., 2019) presents a conundrum for those athletes who need an extensive ROM and hence extensive SS prior to their sport in order to perform their sport actions optimally (e.g., gymnastics, ballet, figure skating, martial arts, and others). We speculated whether the possible benefits of extensive (i.e., 180 seconds per muscle group), high intensity (to the point of maximal discomfort) SS on ROM, performed hours before activity followed by a full dynamic warm-up immediately before activity would counterbalance the mechanisms underlying possible performance deficits (impairments to maximal voluntary isometric contraction (MVIC) forces, electromyography (EMG), and jump heights) while providing greater enhancement of ROM. We hypothesized there would an increased ROM with no significant changes in MVIC forces, EMG, countermovement (CMJ) and drop jump (DJ) heights, if participants were to perform 3 minutes of SS per muscle group, 2 hours before and a full traditional warm-up immediately before the testing. As females are typically less studied in the sport science literature, an analysis of possible sex differences was considered an important aspect of this investigation.

Methods

Experimental design

A repeated measure within-subject factor design was used, which involved a familiarization session (sign consent form, obtain anthropometric measures, explain and practice intervention and testing procedures) and two experimental conditions: 1) prolonged SS (4 x 45 seconds (total duration: 180 seconds) per muscle group) 2 hours prior to a traditional warm-up (mild aerobic activity, SS and dynamic stretching followed by dynamic activity), and 2) an active control condition without the prior SS but still involving a traditional warm-up. Pre- and post-testing involved bilateral hip flexion ROM, unilateral dominant leg knee flexion and extension MVIC, quadriceps and hamstrings EMG as well as bilateral CMJ and DJ heights.

Participants

Seventeen female (9) and male (8) participants between 18-30 years, with an average height and weight of 1.62 (0.05) m and 63.2 (11.9) kg for women and 1.78 (0.04) and 79.3 (20.7) for men respectively. The sample size determination (considering an α-error of 0.05 and a power of 1-β = 0.80) was estimated via G*Power (Universitat Dusseldorf), suggesting a sample size of n = 6-14 for force, n = 3-16 for ROM, and n = 4-13 for EMG measures based on results from Fowles et al. (2000) and Power et al. (2004). All participants were classified as recreationally active and healthy, meaning they engaged in a minimum of 180 minutes of physical activity per week. Any participants who reported an injury within the last three months or an increased risk of thrombosis or varicose veins in the lower extremities were excluded from the study. The study protocol was thoroughly reviewed and approved by the institutional review board of the Memorial University of Newfoundland (ICEHR #20241319-HK). All participants were informed of the experimental procedures and signed a consent form prior to participation.

Testing procedure

Experimental sessions

The participants experienced a series of assessments, including unilateral knee flexion and extension MVIC force of the dominant leg, bilateral CMJ, DJ, and ROM. EMG activity was assessed from the highest MVIC peak force. For the experimental SS condition, there was an initial assessment (pre-testing), approximately 2 hours and 15 minutes prior to the traditional warm-up component. Experimental SS participants then engaged in a session of prolonged SS (180 seconds per muscle group) focusing on the right and left quadriceps and hamstrings. Participants then had a 2-hour rest period. Participants remained in the laboratory for the 2 hours during which they could read, use their computer, or just relax. Following the 2-hour break, the participants performed a 10-minute warm-up, which included 5 minutes of stationary cycling (60-70 rpm at 1 kilopond on a Velotron ergometer (Velotron RacerMate, Seattle, WA, USA), acute SS (4 x 15 seconds per muscle group) and dynamic stretching (2 x 30 seconds). After the warm-up, the post-test assessments (knee flexion and extension MVIC, CMJ, DJ, EMG, and ROM) were conducted (Figure 1).

Active control session

For the control condition, participants did not undergo extensive SS 2 hours prior to the warm-up. They were tested prior to the traditional warm-up. After their pre-test, participants were instructed to perform a 10-minute warm-up, which included 5 minutes of stationary cycling, acute SS (4 x 15 seconds per muscle group), and dynamic stretching (2 x 30 seconds). After the warm-up, the participants engaged in the assessments of knee flexion and extension MVIC, CMJ, DJ, EMG, and ROM (Figure 1).

Bilateral hip flexion range of motion (passive straight leg raise ROM)

Participants were asked to lie supine, ensuring that they were in the initial starting position. An electronic goniometer (EasyAngle: Gait and Motion Technologies, Suffolk, UK) was positioned at the greater trochanter and lateral malleolus while running along the lateral meniscus. The knee joint was immobilized in an extended position by the investigator. To measure *passive straight leg raise* static ROM of both legs, the investigator gently flexed the participant's hip, while keeping the contralateral leg extended until the participant reported feeling a maximal point of discomfort (POD) in their hamstrings.

Unilateral knee flexion and extension MVIC forces (dominant leg)

For unilateral, dominant knee flexion MVICs, participants were seated and strapped (to ensure trunk stability) on a bench with their hips at 90º and knees flexed at 110º, whereas for unilateral, dominant knee extension MVIC, their hips and knees were flexed at a 90º angle.

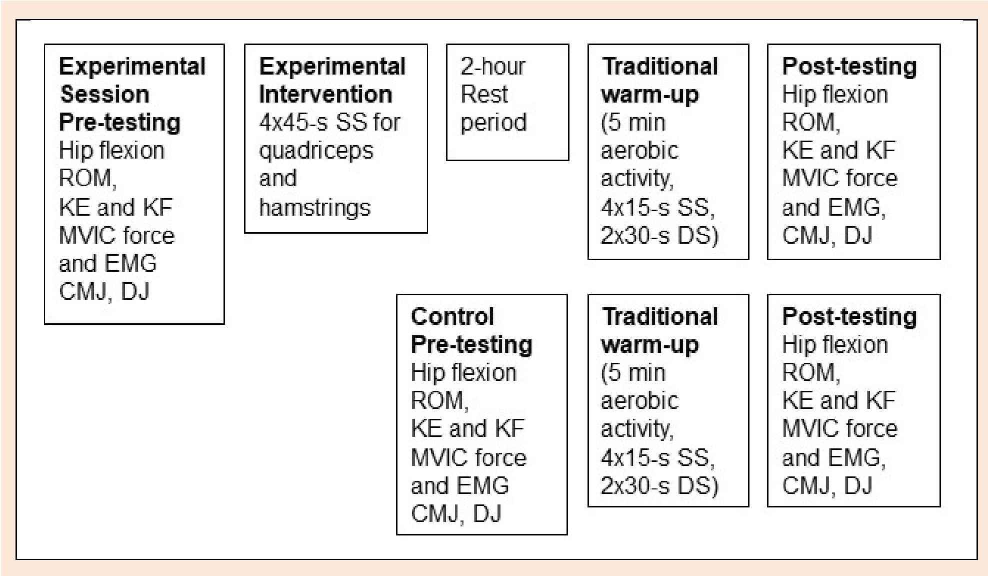

Figure 1. Flow chart of experimental session and control session. CMJ: countermovement jump, DJ: drop jump, DS: dynamic stretching, EMG: electromyography, KE: knee extension, KF: knee flexion, MVIC: maximum voluntary isometric contraction, ROM: range of motion, SS: static stretching.

The ankle was attached using a padded strap, with a high-tension wire connected to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, ON). This setup ensured that force was applied perpendicular to the ankle. Voluntary forces were detected by strain gauges and subsequently amplified (1000x) (Biopac Systems Inc., DA 150: analog-digital converter MP100WSW, Holliston, MA). For knee flexion and extension MVIC testing, participants were instructed to sustain the contraction for a duration of 4 s to measure the peak force. They were guided to exert maximal force as rapidly and powerfully as possible for the full duration.

EMG Testing

To assess muscle activity, surface EMG recording electrodes (MediTrace Pellet Ag/AgCl electrodes, Graphic Controls Ltd., Buffalo, NY) were placed over the mid-belly of the biceps femoris for knee flexion, and the mid-belly of the vastus lateralis for knee extension according to SENIAM recommendations (Hermens et al., 1999). Ground electrodes were securely positioned on the tibial plateau. To ensure optimal skin preparation for all recording electrodes, participants followed a thorough process. This involved the removal of body hair and dead epithelial cells with a razor and abrasive paper around the designated areas, respectively. Following the preparation of the skin, participants cleansed the designated areas with an isopropyl alcohol swab. EMG activity underwent amplification (X 1000), and filtering (10-500 Hz) (BioPac Systems Inc., Holliston, MA). This data was continuously monitored by the software (AcqKnowledge III, BioPac systems Inc., Holliston, Massachusetts, USA) and stored on a computer (HP Pavilion N5310). The mean amplitude of the EMG root mean squared (rms) was calculated from a duration of one second during the peak MVIC force (500 ms before and after the peak force) from the 4 second MVIC duration.

Bilateral Countermovement Jump (CMJ) and Drop Jump (DJ) Testing

For the CMJ, participants stood on the floor and received instructions to execute two bilateral CMJs to achieve the greatest jump height. During these CMJs, participants were asked to rest their hands on their hips (akimbo), and they had the choice to self-select the speed and depth of the knee angle. For the bilateral DJ, participants stood on a platform of 30 cm while akimbo and received instructions to execute two DJs with the instructions to achieve maximal jump height with minimal ground contact time. With both jumps, participants wore a belt at their waist height from which a linear encoder (ChronoJump Bosco System, Australia) was attached. A one-minute rest period was provided between each jump. For each CMJ and DJ, maximum jump height was determined (Chronojump). The highest jump height achieved among the two trials were recorded for further analysis.

Intervention

Using the same stretching procedure as for testing, the SS intervention was performed two hours prior to the warm-up and consisted of four repetitions of 45 seconds at maximal POD with a 15-second rest period between repetitions (total duration of 180 seconds of SS for the hamstrings and quadriceps of both legs) to ensure an effective stimulus. The order for stretching the hamstrings and quadriceps was randomized. Participants would stretch both legs of one muscle group sequentially followed by the other muscle group.

Furthermore, the warm-up (2 hours after the SS protocol) performed before the testing protocol consisted of five minutes of the cycling at submaximal effort (60-70 RPM at 1 kilopond) followed by four repetitions of 15 seconds each of SS for both hamstrings and quadriceps at the maximal POD with 10-second rest periods between the repetitions. Finally, the participants were instructed to perform two minutes of hip flexion and extension dynamic stretching through full ROM for both legs (2x30s each leg).

Statistical analysis

This analysis was performed with SPSS 28 (IBM< Armonk

New York, USA). The data was presented as means (M) ± standard deviation (SD). Before proceeding with the analysis, the Shapiro-Wilk test was applied to check for normal distribution. Reliability was assessed and reported through intraclass correlation coefficient, coefficients of variability and 95% confidence interval (CI) for measurements of MVIC, EMG, CMJ, DJ, and ROM. Additionally, a Levene's test for homogeneity in variance was performed. A 3-way repeated measures ANOVA with 2 conditions (SS two hours prior to warm-up vs. no prior SS), 2 times (pre- and post-tests) and 2 sexes. The Bonferroni test was performed as the post-hoc test to investigate the location of specific differences. Effect sizes was presented as ETA squares (η^2) and categorized as follows: small effect $\eta^2 < 0.06$, medium effect $\eta^2 = 0.06 - 0.14$, high effect $\eta^2 > 0.14$. (Cohen, 1988). Moreover, effect sizes (ES) for the group comparisons were reported with Cohen's d (Cohen, 1988) and categorized as: trivial: d < 0.2, small: d < 0.5, medium: d = 0.5-0.8, and large magnitude effects: d > 0.8. The level of significance was set to p ≤ 0.05.

Results

There were no significant main effects for testing or sex or testing x sex interactions for knee flexion or extension MVIC forces, mean amplitude of the root mean square of the EMG signal, nor for CMJ or DJ height (Table 1).

However, there was a large magnitude main effect for testing for the right ($F_{(2,30)} = 4.887$, p = 0.03, eta^2 = 0.246) and left ($F_{(2,30)} = 6.793$, p = 0.004, eta^2 = 0.312) hip flexion ROM. With left hip flexion ROM, the experimental post-warm-up ROM exhibited a small magnitude significantly (p = 0.002) greater than the pre-SS ROM and control post-warm-up (p = 0.05) (Table 1). Similarly for right hip flexion ROM, the experimental post-warm-up ROM demonstrated a significant small magnitude (p = 0.003) greater ROM than the pre-static stretching ROM and the control post-warm-up (p = 0.046) (Table 1 and Figure 2).

Table 1. Performance and ROM at each testing time. Data are meand (±SD).

Measures	Pre-SS	Pre-control	Post-Warm-up (Exp)	Post-Warm-up (Control)	Exp P-values	Pre-Post-Exp ES	Pre-Post Control ES	Post-Exp vs. Post-Control ES
ROM (Right)	112.2 (21.8)	113.2 (22.2)	116.8 (19.8)	109.3 (21.5)	0.03	0.22	0.13	0.35
ROM (Left)	108.9 (19.3)	109.6 (19.5)	114.4 (19.4)	108.3 (21.7)	0.004	0.28	0.03	0.29
Knee Flexion Force (N)	353.7 (85.8)	353.6 (88.4)	350.3 (102.1)	358.4 (95.8)	NS	0.03	0.05	0.07
Knee Extension Force (N)	521.5 (154.4)	519.6 (159.1)	505.6 (157.9)	506.0 (161.5)	NS	0.10	0.09	0.002
Hamstrings EMG (mV)	0.942 (0.412)	0.951 (0.43)	0.852 (0.447)	0.991 (0.551)	NS	0.21	0.10	0.12
Quadriceps EMG (mV)	1.477 (0.808)	1.39 (0.83)	1.428 (0.851)	1.315 (0.663)	NS	0.059	0.22	0.13
CMJ Height (m)	0.266 (0.093)	0.255 (0.095)	0.272 (0.092)	0.259 (0.089)	NS	0.069	0.076	0.14
DJ Height (m)	0.253 (0.100)	-	0.251 (0.094)	0.257 (0.089)	NS	0.021	0.045	0.06

CMJ: countermovement jump, DJ: drop jump, EMG: electromyography, ES: effect sizes, Exp: experimental (SS 2 hours prior to warm-up), NS: non-significant, ROM: range of motion in degrees, SS: static stretching.

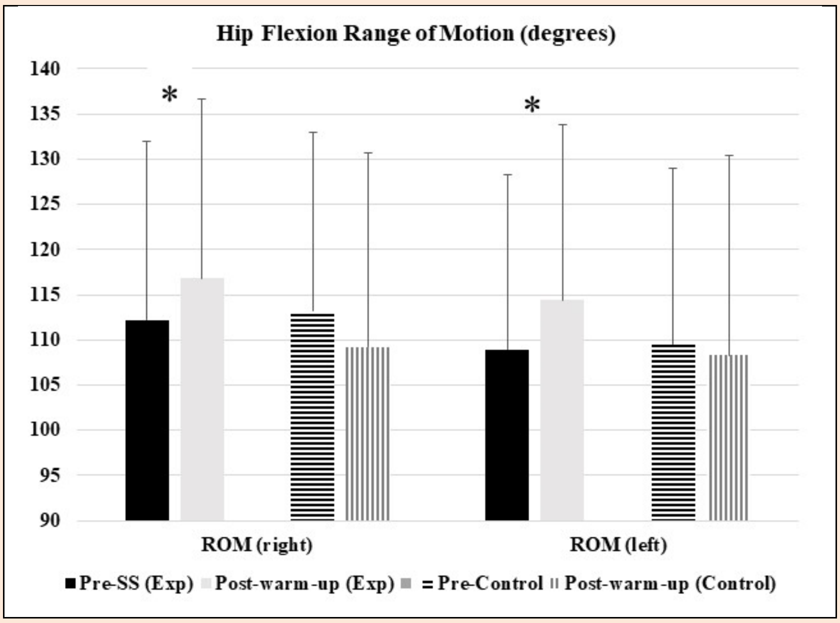

Figure 2. Hip flexion (hamstrings) range of motion. * indicate significant differences between pre- and post-testing. Exp: Experimental condition, ROM: range of motion, SS: static stretching.

There were no significant sex interactions but there was a significant large magnitude between subjects' effect for sex for the left hip flexion ROM ($F_{(1,15)}$ = 7.051, p = 0.018, eta^2 = 0.320). Women presented 122.6° ± 22.25 compared to significantly lower 99.95° ± 11.55 (ES: 1.34) ROM for the men. Similarly, for the right hip flexion, there was a significant large magnitude between subjects effect for sex ($F_{(1,15)}$ = 9.056, p = 0.009, eta^2 = 0.376). Women presented 122.3° ± 21.79 compared to significantly lower 100.6° ± 10.66 (ES: 1.29) right hip flexion ROM for the men.

Discussion

The major findings of this research were that a preliminary extensive SS routine (4 x 45-s SS for the hamstrings and quadriceps respectively) performed two hours before a brief warm-up involving short durations of SS (4x15-s) and DS (2x30-s) induced a small magnitude greater ROM than just the traditional warm-up. Furthermore, there were no performance decrements associated with the prior prolonged stretching session. In addition, as seen in prior research, women had much greater large magnitude absolute ROM than men, however there were no sex and testing interaction effects suggesting there was no sex effect of the stretching intervention. The results of this study are unique as there are no other studies examining the effects of extensive SS on performance performed 2-hours prior to a traditional warm-up. Athletes who need a more extensive ROM in their sport while still performing explosive or powerful contractions may consider adding a more extensive volume of SS, two hours prior to a traditional warm-up and subsequent competition to augment their ROM without fear of performance impairments.

Range of motion

Hip flexors (hamstrings) and extensors (quadriceps) exhibited a significant, small magnitude more extensive ROM with SS 2-hours prior to a warm-up compared to just a traditional warm-up using 60-seconds of SS and DS respectively. These findings of 4.1% and 4.9% ROM increases in the right and left hip flexors respectively, align with Power et al. (2004) who found a 6% hip flexors ROM increase 120 minutes after six static stretches held for 45-s each. While the present study imposed 180-s of SS per muscle group, Power et al. utilized 270-s.

Acute increases in ROM have been attributed to neural, morphological, and psychological factors. Prolonged SS effects on muscle spindle reflex disfacilitation (decreased afferent excitability), decreased voluntary muscle activation, and persistent inward currents (PICs: amplification of motoneuron gain) could increase muscle relaxation, but these effects would not persist for two hours after stretching (Behm et al., 2015; 2021d). The insignificant changes in EMG activity two hours after prolonged stretching in the present study corroborates the previously reported lack of prolonged stretch-induced deficits in voluntary activation. Stress and increased muscle temperatures could induce thixotropic effects decreasing tissue viscosity thus reducing resistance to movement (Behm et al., 2015; 2021d; Magnusson et al., 1995). Although not presently studied, it is speculated that thixotropic effects due to enhanced muscle temperatures and activity would not be expected to be sustained for two hours post-SS. An increase in pain or stretch threshold is a ubiquitous mechanism for increasing ROM in the literature (Behm et al., 2015; 2021d; Magnusson et al., 1996). Once again, the possibility of an enhanced pain threshold has not been studied two hours post-stretching. Decreases in joint stiffness are reported following an acute bout of SS (Behm et al., 2015; 2021d; Kay et al., 2015; Magnusson et al., 1996). Whether these changes in joint stiffness can be attributed to a more compliant muscle (Konrad et al., 2017) is difficult to conclude. Warneke et al. (2024) in their meta-analysis determined that only long-stretching durations sufficiently decreased muscle stiffness acutely with no observed effects on tendons. Another Konrad et al. (2019) report also found stretch-induced increases in muscle elongation but did not find changes in tendon stiffness. Although, this effect has also not been studied at a two-hour post-SS period, we would speculate that it is possible that joint (primarily muscle) stiffness decreases, or increased compliance might be a possible contributor to the enhanced ROM at this time.

The greater absolute ROM with women found in this study is in accord with much of the literature (Behm 2024, Marshall and Siegler 2014). Greater female ROM has been attributed to a greater tolerance to stretching than males, and lower musculotendinous stiffness (Hoge et al., 2010; Morse, 2011). However, recent reviews have reported that the relative change in ROM with either acute (Behm et al., 2022) or chronic (Konrad et al., 2024; Lima et al., 2019) stretching is not significantly different between the sexes. The lack of testing x sex interactions in this study is also in agreement with these reviews.

Muscle Voluntary Isometric Contraction (MVIC) force and EMG

There were no significant differences in the knee extension and knee flexion MVIC forces or EMG activity when comparing pre-SS, and post-warm-up. One hour after 33 minutes of plantar flexors stretching (13 x 135-s), Fowles et al. (2000) reported 8-12% decreases in MVIC torque. Motor unit activation and EMG were significantly depressed immediately after SS but recovered within 15 minutes in the Fowles et al. (2000) study. Power et al. (2004) found 10.4% and 16% impairments in quadriceps MVIC torque and EMG respectively, two hours after 3 x 45-s of SS. Twenty-four hours after 2 sets of 7 minutes and 30-s SS (2 x 30-s SS with 15-s passive recovery) for the quadriceps, hamstrings, calves, adductors, and hip flexors, Haddad et al. (2014) discovered small magnitude deficits in the 5-jump test and 10-30 metre sprint times. Earlier reviews on the effects of an acute bout of prolonged stretching without a traditional warm-up reported typical performance (strength, power, sprint sped jump height) decrements of 3-7% (Behm and Chaouachi, 2011; Behm et al., 2015; 2021d; Chaabene et al., 2019; Kay and Blazevich, 2012).

However, more recent research has shown that when SS is incorporated into a full traditional warm-up, the performance deficits are typically trivial. A number of studies have shown trivial effects of SS on subsequent performance when a full dynamic warm-up has been included (Blazevich et al., 2018; Murphy et al., 2010; Reid et al., 2018; Samson et al., 2012). These findings have also been reflected in related reviews (Behm and Chaouachi, 2011; Kay and Blazevich, 2012; Behm et al., 2015; 2021d; Chaabene et al., 2019; Lima et al., 2019).

Similar to the prior discussion on ROM mechanisms, the reports of lower neuromuscular activation, muscle spindle reflex disfacilitation, and attenuated persistent inward currents (Behm et al., 2013; 2015; 2021d, Trajano et al., 2014; 2017; 2020; 2021; Walsh, 2017) would not be expected to still affect performance after 2 hours of recovery. Similarly, the concepts of mental energy deficit (decreased ability to focus, concentrate or activate after preceding exercise) (Halperin et al., 2015) or an increased perception of effort with subsequent activities after the initial activity (Steele, 2020) would be speculated to also subside after two hours of rest. According to Konrad et al. (2019) and Mizuno et al. (2013), decreases in muscle stiffness were only observed at 5 or 5-10 minutes respectively after 5 repetitions of 60-s SS. Although unlikely, if decreased muscle stiffness was still present two hours post-SS, the less efficient transfer of force from muscle and tendon to bone (increased electromechanical delay) could have been offset by the increased corticospinal and reflexive neural excitability as well as the increased muscle fibre temperature, and decreased tissue visco-elasticity (thixotropic effect) of the dynamic stretching activities (Behm et al., 2015; 2021d) in the traditional warm-up component. Decreased hamstrings visco-elasticity was also reported one hour after 5 static stretches of 90-s each (Magnusson et al., 1995).

Countermovement (CMJ) and Drop Jump (DJ) height

The lack of change in CMJ and DJ height are in accord with much of the literature that incorporates a traditional dynamic warm-up with the SS (Murphy et al., 2010; Reid et al., 2018; Samson et al., 2012). A review by Lima et al. (2019) found that there were no jump height impairments resulting from a combination of prolonged SS (>60s per muscle group) and dynamic stretching. Although Power et al. (2004) found CMJ and DJ deficits post-SS of approximately 3-10% and 2-5% after two hours, they were not statistically significant.

If the hypothesis that a more compliant musculotendinous unit (i.e. decreased visco-elasticity: Magnusson et al., 1995) contributed to an increased ROM after two hours, it could have negatively impacted jump heights. The less efficient transfer of force with less stiffness would not help to augment force development with a rapid stretch shortening cycle (SSC) (Aura and Komi, 1986; Bosco et al., 1982; McCarthy et al., 2012). Although the participants were requested to contract as rapidly as possible in the concentric phase of the CMJ and to have a brief contact period (rapid eccentric component) with the DJ, they were recreationally active participants and not elite athletes. Hence, it is possible that they exhibited slower SSC with longer amortization or transition periods than explosive athletes. Less rapid SSC actions can benefit from a more compliant musculotendinous unit as the slower transfer of force temporally aligns better with the longer transition from eccentric to concentric contractions (Chauoachi et al., 2010; Godges et al., 1989; Wilson et al., 1992).

Limitations

This study was subject to several limitations that should be considered when interpreting the results. Every study can benefit from a greater number of participants to strengthen the power of the analysis. A great number of participants for each sex might have provided more statistical power to possibly reveal significant sex x time interactions. The study's findings are also limited by the specific characteristics of the sample population (recreationally active) and may not directly apply to other populations (e.g., elite athletes, seniors, children and others). The findings are also specific to the constraints inherent in the study design, including the duration and intensity of the stretching protocol and the timing of measurements. For example, implementing an extensive SS component, two hours before the traditional warm-up and competition or practice may be difficult in a time constrained environment (e.g., practice or game starts soon after school, so class time would interfere with this stretching schedule). These limitations underscore the need for cautious interpretation and suggest paths for future research to enhance the validity and generalizability of findings in stretching interventions.

Conclusion

This study investigated the effects of a prolonged SS routine performed two hours prior to a warm-up, compared to a control condition, on various measures of muscle flexibility, strength, and jump performance. The results revealed significant, small magnitude increases in hip flexion ROM following the prior (2-hours) SS intervention, with greater large magnitude, absolute ROM observed in women compared to men. However, no significant changes were found in knee flexion/extension MVIC forces, EMG activity, or vertical jump heights between the experimental and control conditions. These findings suggest that while extensive SS may enhance ROM, possible negative impacts on other performance measures may be trivial when combined with a subsequent warm-up two hours after stretching. A lack of research on the impact and mechanisms of stretching before a 2-hour period on performance needs further research.

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Key points

- There were significant increases in hip flexion ROM following the prior (2-hours) of static stretching.
- Greater absolute range of motion was observed in women compared to men.
- The prior (2 hours) extensive static stretching did not induce significant impairments in knee flexion/extension MVIC forces, EMG activity, or vertical jump heights.
- Whereas extensive static stretching may enhance ROM, possible negative impacts on other performance measures may be trivial when combined with a subsequent warm-up two hours after stretching.

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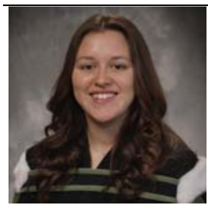

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