Self-Myofascial Release Does Not Improve Functional Outcomes in 'Tight' Hamstrings

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Self-myofascial release does not improve functional outcomes in 'tight' hamstrings

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ABSTRACT

Purpose: Self-myofascial release (SMR) is a common exercise and therapeutic modality shown to induce acute improvements in joint range of motion (ROM) and recovery; however, no long-term studies have been conducted. Static stretching (SS) is the most common method used to increase joint ROM and decrease muscle stiffness. We hypothesized that SMR paired with SS (SMR+SS) compared with SS alone over a 4-week intervention would yield greater improvement in knee extension ROM and hamstring stiffness. **Methods**: 19 young males (22 ± 3 yrs.) with bilateral reduced hamstring ROM had each of their legs randomly assigned to either a SMR+SS or SS group. The intervention consisted of 4 repetitions of SS each for 45 s or the identical amount of SS preceded by 4 repetitions of SMR each for 60 s (SMR+SS) and was performed on the respective leg twice daily for 4 weeks. Passive ROM, hamstring stiffness, rate of torque development (RTD) and maximum voluntary contraction (MVC) were assessed pre- and post-intervention. **Results:** Passive ROM ($P<0.001$), RTD and MVC ($P<0.05$) all increased after the intervention. Hamstring stiffness towards the end ROM was reduced post-intervention ($P=0.02$). There were no differences between the intervention groups for any variable. **Conclusion:** The addition of SMR to SS did not enhance the efficacy of SS. SS increases joint ROM through a combination of decreased muscle stiffness and increased stretch tolerance.

Keywords: Stretching, Foam Rolling, Performance, Myofascial Release, Stiffness

INTRODUCTION

Stretching and myofascial release are common modalities used in rehabilitation, fitness and athletic settings to recover skeletal muscle function[1–3]. Myofascial release is primarily a hands-on technique similar to massage therapy that involves the application of pressure on 'restricted' areas of fascia or 'trigger points' to restore muscle function. Self-myofascial release (SMR), or self-massage, has been proposed to be a substitute for myofascial release[1–4]. Despite the wide spread adoption of SMR, the effects of SMR on muscle stiffness and function over a long duration have not been examined.

Static stretching (SS) increases joint ROM[5–10] potentially by altering muscle[6,7] or muscle-tendon unit[8,11] stiffness and stretch tolerance[9,10,12]. Stretch tolerance refers to the personal tolerance of discomfort towards the end ROM of the stretch[12]. Muscle stiffness is defined as the passive resistance to the stretch throughout a ROM and is proportional to the slope of the passive torque-angle curve[13]. SS can acutely increase ROM[5] and decrease passive stiffness[11]; however, acute SS often results in decreased maximum voluntary contraction (MVC) torque or force output, especially when the duration of the stretch exceeds 60 s.[14]. Chronic SS can increase joint ROM[6–10], possibly via a change in muscle stiffness[6,7], though it's effect on MVC and rate of torque development (RTD) is inconclusive[15]. Whether there are muscle performance, such as MVC and RTD, decrements as a result of chronic SS and whether the changes in ROM are a result of stretch tolerance or change in tissue property has yet to be fully elucidated.

A single bout[16] or 4 days of massage[17] enhances ROM[16] and decreases the perceived amount of delayed-onset of muscle soreness[17] with no effect on MVC[16,17] or RTD[16]. With the ability to enhance ROM without negatively affecting performance, SMR may be an advantageous alternative to SS. The intended purpose of SMR, commonly applied via a foam roller, is to increase joint ROM[1,2,4,5,18,19], alleviate muscle soreness[1,3,20], release connective tissue 'adhesions' or painful 'trigger points' and decrease muscle/muscle-tendon unit stiffness. SMR appears to be an effective modality to aid in recovery from intense exercise[1,3,20] and to acutely increase ROM[1,2,4,5,18,19,21] without inducing the acute negative effects on performance[1,2,4,5,20,21] associated with SS[5,22]. SMR is commonly performed before SS because it is proposed that SMR relieves connective tissue 'adhesions' allowing the subsequent stretch to better affect the target muscle. To date, no studies have examined if chronic SMR paired with SS can alter either hamstring stiffness or performance.

The aim of this investigation was to compare the effects of 4 weeks of SS alone versus a combination of SMR and SS on joint ROM and hamstring stiffness using a within-subject, unilateral design. The secondary purpose was to determine if SS or SMR with SS affected skeletal muscle function as assessed by MVC and RTD. We hypothesized that performing SMR before SS would augment the improvement in ROM and muscle stiffness relative to SS alone with no effect on MVC or RTD.

METHODS

Subjects. Twenty healthy, recreationally active young males (22 ± 3 yrs.) were recruited. Participants were not receiving any form of myofascial release or practicing SMR outside the study, were free of any lower body injuries within the past 6 months, were not performing regular SS, and had bilateral hamstring tightness[23] assessed on the first day. The study was approved by the McMaster University Research Ethics Committee (reference# SREC 2013 52) and was conducted in compliance with the most recent version of the Declaration of Helsinki. All participants provided informed written consent.

Design. Participants reported to the laboratory for 3 visits and the same investigator took all measures. During the first visit (familiarization) participants were assessed for bilateral hamstring tightness[23] and oriented to the Biodex dynamometer (Biodex, Shirley, NY, USA). To familiarize participants with the apparatus they were taken through both the passive ROM/stiffness and MVC/RTD measurements. One week later they came in for a second visit (pre) and the procedures from the familiarization visit were repeated. After pre measures, participant's legs were randomized by leg-dominance (based on MVC) into one of two conditions: SS only (SS) or SMR and SS (SMR+SS). Each participant was instructed on how to perform the SMR and SS procedures correctly and provided with written instructions. Upon completion of the 4-week intervention, participants returned for their third visit (post) where all measurements were repeated (Figure 1). The post testing took place the morning (~12h) after completion of the last session of the intervention. No significant differences were found for any of the test variables between the familiarization testing and the pre testing indicating that subjects were well familiarized and no learning effect occurred between testing sessions. The coefficient of variation for joint ROM between familiarization and pre testing measurements was 3.0%.

Participants were instructed to maintain any current exercise regimes throughout the study. In addition, participants completed a log listing the time of each completed session. The average compliance with the intervention was 81% ± 14% (mean ± SD). Participants who completed less than 60% of the prescribed sessions were excluded from the analysis (n=1). There was no correlation between compliance and any outcome measures. A compliance of >60% required that the participants performed the intervention more than once per day for 4 weeks. Compliance was identical in both groups due to the nature of the within-subject design.

Stretching Protocol. Participants performed the SS and SMR+SS procedures once in the morning and once in the evening for 28 consecutive days. Each session consisted of 4 hamstring stretches held for 45 s with a 15 s rest between stretches[9]. The stretches were performed in a seated position with the target leg elevated and supported straight in front of the participant. The participants leaned forward with a straight back to a point where they experienced a "strong but not painful stretch sensation". Participants were instructed maintain a slight lumbar lordosis (neutral spine) and to avoid excessive pelvic tilt. The opposite leg was flexed at the knee and hip while slightly abducted to ensure that the hamstring muscle group was not under any tension.

SMR Protocol. The SMR+SS leg followed the same SS regimen as the SS leg with the addition of SMR on a custom-made 45.72 cm hollow polyvinyl chloride pipe roller constructed of a 10.16 cm outer diameter and a thickness of 0.51 cm. This type of roller was used as it places more pressure on the fascia compared with a Bio-foam roller made from uniform polystyrene foam[24]. Participants performed the SMR protocol before commencing the SS protocol on the SMR+SS randomized leg. Participants were instructed to place as much of their body mass as possible onto the roller while stacking their opposite leg on top of the leg being rolled for added pressure. The participants started at the origin of the biceps femoris (ischial tuberosity) and rolled distally, using small undulating movements, towards the back of the knee similar to a previously published acute protocol[18]. Each repetition from origin to insertion lasted a total of one minute. Once the roller reached the back of the knee, participants were instructed to return the roller to the starting position in one fluid motion. Participants rested for 15-30 s between each of the 4 repetitions.

Passive range of motion test. Passive knee extension ROM was measured using a Biodex dynamometer. The thigh rested on a specially constructed wedge which elevated the thigh to 30 degrees from the horizontal similar to previously published articles (Figure 2)[6,9]. The purpose of the elevated thigh was to prevent the participants from reaching complete (180 degrees) knee extension. The lever arm attachment was placed approximately 2 cm proximal to the lateral malleolus. The distal thigh, pelvis, ankle, and chest were firmly secured with straps to minimize movement during the stretch maneuver. A small 2 cm pad was placed behind their lower back to maintain lumbar lordosis during the stretch procedure[6]. Analog torque and knee joint angle signals were A-to-D converted by a Powerlab data acquisition system (ADInstruments, Bella Vista, Australia) at 2000 Hz and were recorded with LabChart 7 Pro (ADInstruments, Bella Vista, Australia).

Seated in the dynamometer, the participant was given full control of the stretch placed on their hamstrings. Participants were told to relax completely during the stretch. Electromyography was not included as an outcome measure because previous work has shown that agonist muscle activation during comparable procedures is negligible[9]. Testing unilaterally, participants leaned their head back and closed their eyes to remove visual feedback. Participants pressed a hand-held button to initiate extension of the dynamometer arm that elevated their ankle, therefore extending their knee, at a velocity of 5 degrees/s until they felt a “strong but not painful stretch sensation”. At this point they pushed the same button and their ankle was immediately taken back down to neutral (knee flexed at 90 degrees). Following 5 consecutive passive knee extension measures, the participants performed three, 5 s MVCs at 150 degrees of knee extension (~75% of maximal end range for this population). 30 s of rest was taken between contractions. Acute SS of a single muscle group lasting shorter than 60-90 s, as performed in the dynamometer testing described above, does not impair or impact subsequent MVCs[14]. Regardless of intervention randomization, each participant completed the measurements on the right leg before the left assuring counterbalance of testing order between conditions.

Data Analysis. All calculations were performed offline using custom Matlab scripts[25,26]. Although 5 trials were performed, only the average of the last 3 trials was used for the stiffness and ROM measurements. Torque (MVC and passive) and knee joint angle were low pass filtered at 20 Hz. Maximal ROM was calculated as the greatest knee joint angle recorded before the dynamometer arm was returned to the starting angle. Peak passive torque was measured at the maximal ROM. Instantaneous hamstring stiffness was calculated as the slope of a 4th order polynomial fitted to the torque angle relationship at a given angle[25]. The MVC for each trial was taken as the highest torque achieved on the low pass filtered waveform. The first derivative of torque with respect to time was calculated and the peak value was taken as the RTD.

Statistical Analysis. Statistical analyses were performed using Statistical Package for Social Sciences (SPSS, Version 10.0, Chicago, IL). A two-way repeated measures analysis of variance

(ANOVA) was utilized with time (pre and post) and condition (SS and SMR+SS) as the experimental factors. The dependent variables were ROM, MVC, RTD and peak passive torque. Stiffness was first analyzed with a two-way repeated measures ANOVA with condition and maximal angle as the experimental factors. A three-way repeated measures ANOVA was then used with time, angle and condition as the experimental factors. Sidak's post hoc method was used where appropriate to isolate specific pairwise differences. Significance was set at alpha ≤ 0.05. Results are reported as mean ± SEM.

RESULTS

Passive ROM. The intervention resulted in a significant increase in passive ROM over time ($P < 0.001$) using the pooled mean from 172 ± 12 to 181 ± 16 degrees (Figure 3). This equates to a percent change of 5%. Passive ROM increased by 8 ± 2 degrees in the SS leg and 9 ± 2 degrees in the SMR+SS leg with no difference between conditions ($P = 0.38$). Cohen's effect size value for the pooled means ($d = 0.64$) suggests a moderate to high practical significance.

Peak Passive Torque. The intervention resulted in a significant increase in peak passive torque ($P = 0.03$) using the pooled mean increased from 53 ± 12 to 60 ± 17 Nm. This equates to a percent change of 13%. Peak passive torque increased 5 ± 8 Nm in the SS leg and 6 ± 14 Nm in the SMR+SS leg with no difference between conditions ($P = 0.96$). Cohen's effect size value for the pooled mean ($d = 0.42$) suggests moderate practical significance.

Stiffness. Muscle stiffness was assessed every 10 degrees starting at 110 degrees of extension (Table 2). As expected, hamstring stiffness increased as knee angle approached full extension ($P < 0.001$). There was a time by angle interaction such that stiffness towards the end of the ROM was reduced post intervention ($P = 0.02$). There was no interaction between time and condition at the same angle measured post-training ($P = 0.264$). Interestingly, there was a tendency for a significantly lower stiffness at the pre end-ROM measured post-training compared to pre-training ($P = 0.064$). The pre end-ROM measured post-training was also significantly lower than the stiffness at the post-intervention end-ROM ($P = 0.002$). There was no difference in stiffness between the pre end-ROM measured pre-training and the post end-ROM measured post-training ($P = 0.18$; Figure 4). There was no effect of condition on stiffness at any joint angle ($P = 0.52$). Using the pooled mean, Cohen's effect size for the stiffness at the subject's pre-intervention maximal passive ROM ($d = -1.45$) suggests large practical significance.

Performance. Using the pooled mean, MVC increased from 141 ± 27 to 146 ± 30 Nm ($P=0.013$). This equates to a percent change of 4%. MVC increased 5 ± 9 Nm and 2 ± 9 Nm in the SS and SMR+SS groups respectively with no difference between conditions ($P = 0.313$). . RTD (pooled mean) also increased from 594 ± 217 to 639 ± 249 Nm/s ($P=0.012$). This equates to a percent change of 8%. RTD increased 41 ± 104 Nm/s and 48 ± 112 Nm/s in the SS and SMR+SS groups respectively with no difference between conditions ($P = 0.410$; Table 3). Cohen's effect size values for the pooled means of MVC ($d = 0.13$) and RTD ($d = 19$) suggest low practical significance.

DISCUSSION

We aimed to evaluate the effects of 4 weeks of SS versus SS preceded by SMR via a hard plastic roller. To our knowledge, this is the first study to date to longitudinally, as opposed to acutely[18,19], evaluate the effects of SS with SMR. To increase the power to detect differences in our outcomes, we employed a within-subject design. Our principal discovery was that, in persons with tight hamstrings[23], there was no benefit of adding SMR to a SS regime on hamstring ROM, stiffness, or muscle performance.

In contrast to our study, Skarabot et al[19] compared the acute changes of ROM to a single bout of either SS, foam-rolling, or a combination of the two. The authors concluded that, via a weight-bearing lunge test, the SMR+SS group had a greater increase in passive ROM than the SMR group, but not the SS group[19]. Our study aimed to replicate a similar model over a longer period of time. Renan-Ordine et al[27] provided participants with soft-tissue trigger point manual therapy, a form of myofascial release, before SS for 4 weeks. They[27] concluded that, compared to a SS-only group, after 4 weeks participants who received trigger point therapy in combination with SS had less plantar heel pain. Though we did not measure pain, we hypothesized that these results, in conjunction with the acute results from Skarabot et al[19], suggest that SMR may provide additional benefits when combined with SS relative to just SS.

Mohr et al[18] had subjects with tight hamstrings complete 6 bouts of either SS, SMR, or SMR+SS each separated by 48 hours. Analogous to our study, Mohr et al[18] targeted only the hamstrings using a similar SMR protocol. Importantly, these authors measured joint ROM immediately following the final bout of the intervention. This means that any effect could have been a result of the acute influence of SMR and/or SS. The authors concluded, comparable to Skarabot et al[19], that performing SMR before SS leads to greater increases in ROM relative to SMR or SS alone[18]. Based on our data, we propose that the results from Mohr et al[18] are likely the result of an acute effect of SMR on ROM as has been shown before[1,2,4,5,19].

In earlier studies, SMR has been shown to acutely increase ROM[1,2,4,5,18,19,21], enhance vascular function[28], augment recovery following exercise[1,3,20], and reduce pain sensation[3,29]. Equivocal results have been found showing either an increase[5] or no effect[2,4,20,21] of SMR on MVC. The studies that measured SMR in addition to SS[18,19] did not measure muscle performance. The present study found that SMR had no effect on MVC or RTD. Though research has shown that SS acutely reduces force output[14,22], over a 4-week period, we found that both MVC and RTD were increased regardless of the treatment condition. We recognize that variability in the participant's physical activity level during the study may have influenced the results; however, subjects were instructed to maintain habitual physical activity throughout the trial. As such, we hypothesize that the small increase in both MVC and RTD is demonstration that 4 weeks of SS or SMR+SS does not negatively impact muscle function.

We aimed to quantify whether or not changes in muscle stiffness underpinned the observed changes in ROM. It is known that SS both acutely[22] and chronically[6,8,9,23] increases ROM. Several hypotheses have been suggested to explain the SS-induced increase in muscle ROM such as an increase in stretch tolerance[9,10,12] and fascicle length[8] or a decrease in muscle[6,7] and muscle-tendon unit[8,11] stiffness. The increase in muscle and muscle-tendon unit stiffness has been proposed to be a result of an increased compliance of local connective tissue, chiefly perimysium[30]. There are, however, opposing findings regarding the effect of SS on hamstring stiffness[6,7,9]. For example, Magnusson et al[9], after three weeks of passive SS, found no decrease in passive resistance with the increased ROM suggesting no change in the mechanical or viscoelastic properties of the muscle. In contrast, Marshall et al[7] found that a 4-week SS regimen increased hamstring extensibility by 21% and decreased hamstring stiffness by 31%. A secondary finding of our study was that SS performed twice daily for 4 weeks with or without SMR decreased hamstring stiffness towards the end-ROM. The decrease in stiffness measured post-intervention at the angle of peak pre-intervention ROM (Figure 4) suggests that changes in the mechanical properties of the muscle at least partially influenced the observed increase in ROM. However, it is important to also highlight that the peak passive torque recorded at the end-ROM increased following the intervention. It is likely that, along with changes in mechanical/connective tissue properties, an increase in stretch tolerance is responsible for the greater ROM induced by a chronic SS regimen.

There are several potential limitations to our study design. First, the present study exclusively rolled the posterior thigh whereas in other acute SMR studies, such as a study by Macdonald et al[1], participants rolled anterior, lateral, posterior and medial aspects of the thigh and gluteal muscles. It is also possible that tightness in the hamstring muscle group was not actually limiting knee extension ROM in some participants; thus, since only the posterior thigh was rolled in the current study, the muscle that limited ROM may not have been targeted. However, the observed increase in ROM does suggest the hamstrings played some role in limiting knee extension ROM. The application of SMR is undoubtedly dependent on the specific location and pressure an individual places on that area. Consequently, it is challenging to accurately (and reproducibly) control the SMR stimulus between individuals. Nonetheless, we propose that the control of pressure in which SMR is applied in the therapeutic setting is very similar to the degree that it was controlled in our study. We used a SS-only leg as a control primarily so we could perform a within-subject design and because our goal was to examine the additive effects of SMR on SS. This study design has been used over a 6-week SS intervention and shown to result in no crossover effect between the control and SS leg[10]. Again, the rationale of performing SMR before SS was that SMR is proposed to 'prime' the muscle, potentially via local increases in muscle temperature and blood flow[28]. Such effects would allow for a greater effect of the SS stimulus on the muscle. Due to our study design choice it is obviously not possible to draw conclusions about the effect of SMR in isolation of SS.

PRACTICAL APPLICATIONS

Previous work has shown that SMR can increase ROM acutely[1,2,4,5,18,19,21] without negatively impacting performance[2,4,5,20,21], improve recovery from exercise[1,3,20] and in some cases reduce pressure pain threshold[3,29]. On the other hand, chronic SS has been shown many times to increase ROM[6–10]. Based on previous findings and the results from the present study, SMR may be an effective modality used before exercise or competition to increase ROM without depressing performance. Additionally, SMR is an acceptable strategy to improve the recovery after intense exercise or competition. SMR should also be tested as a method to reduce pain, which may have ample therapeutic implications. SS should be used in cases where the goal is to chronically increase joint ROM. At this point there is no evidence to support the repeated use of SMR in conjunction with SS if the purpose is to increase ROM.

CONCLUSION

In agreement with previous reports we have shown, in regards to the hamstring muscle group, that SS is an effective means of increasing joint ROM. There were no muscle performance decrements after performing 4 weeks of either SS or SMR and SS. The mechanisms that underpin the increase in ROM appear to be a combination of decreased muscle and/or muscle-tendon unit stiffness along with an increase in stretch tolerance. The addition of SMR to a high volume of SS was found to result in no further benefit for any functional outcome. Future work should seek to determine the effect of chronic SMR performed without SS and investigate the mechanisms by which acute SMR and chronic SS increase ROM and recovery.

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FIGURE LEGENDS

FIGURE 1 - Study schematic. Measurements include supine passive ROM, passive ROM, muscle stiffness, MVC and RTD. MVC - maximum voluntary contraction. RTD - rate of torque development.

FIGURE 2 - Dynamometer illustration with 30 degree wedge.

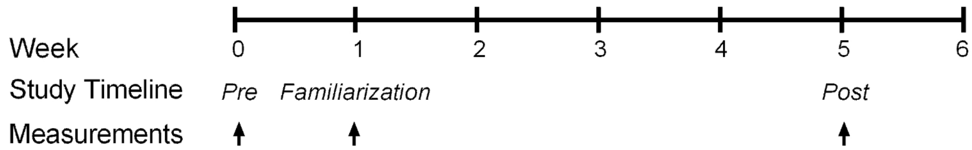
FIGURE 3- Terminal ROM. SS - static stretching only. SMR+SS - self-myofascial release and static stretching. The *y* axis displays the angle in degrees. The *x* axis displays the group. * indicates P<0.05.

FIGURE 4 - Changes in stiffness at terminal ROM pre and post intervention. SS - static stretching only. SMR+SS - self-myofascial release and static stretching. The *y* axis displays the stiffness in $Nm^{\circ -1}$. The *x* axis displays the time and angle in which hamstring stiffness was measured including the: i) terminal ROM at the beginning of 4 weeks ii) terminal ROM at the beginning of 4 weeks, evaluated after the 4 wk intervention iii) terminal ROM at the end of the 4 week intervention. * indicates P=0.064. ** indicates P<0.05.

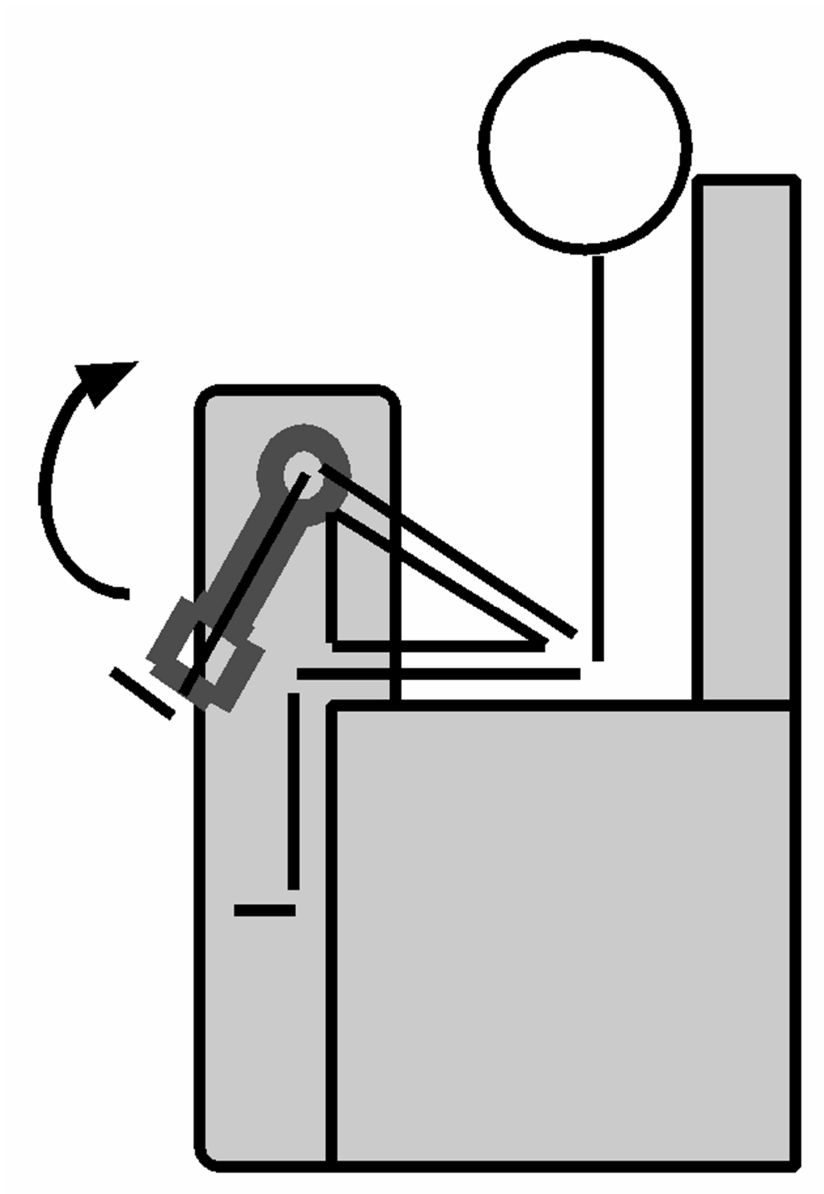
TABLE 1 - The participant characteristics displayed as mean ± SE.

TABLE 2 - Hamstring stiffness pre- and post-intervention measured every 10 degrees for both groups in $N \cdot m^{\circ -1}$. Values are in mean ± SE. * indicates significant difference from pre ($P=0.064$)

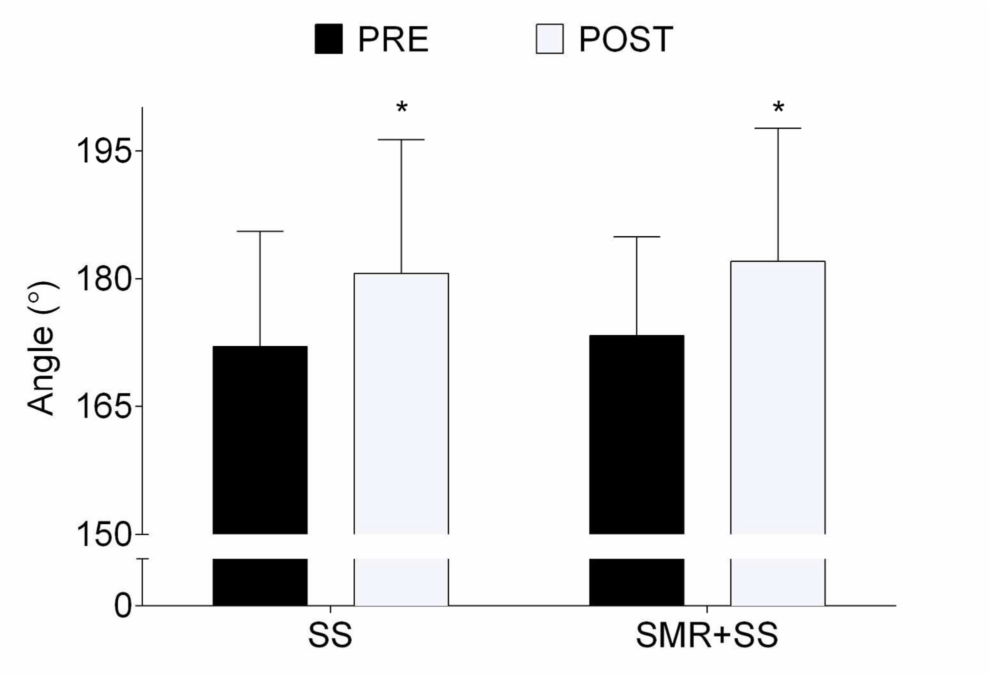
TABLE 3 - MVC - maximum voluntary contraction. RTD - rate of torque development. Data is displayed as mean ± SE. * indicates significant difference from pre ($P<0.05$)



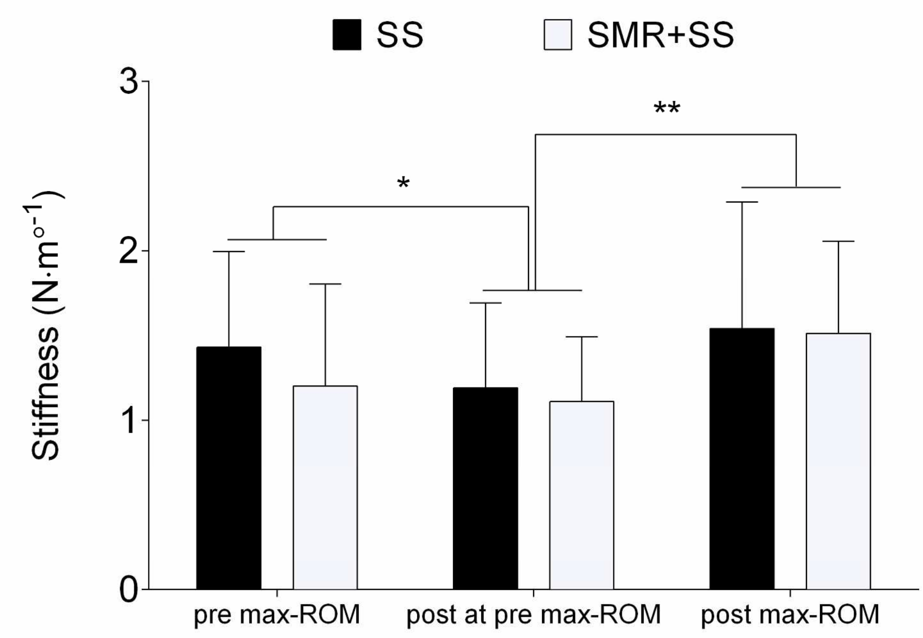
Study schematic. Measurements include supine passive ROM, passive ROM, muscle stiffness, MVC and RTD. MVC - maximum voluntary contraction. RTD - rate of torque development.
182x29mm (300 x 300 DPI)



Dynamometer illustration with 30 degree wedg
53x77mm (300 x 300 DPI)



Terminal ROM. SS - static stretching only. SMR+SS - self-myofascial release and static stretching. The y axis displays the angle in degrees. The x axis displays the group. * indicates P<0.05.
202x137mm (300 x 300 DPI)



Changes in stiffness at terminal ROM pre and post intervention. SS - static stretching only. SMR+SS - self-myofascial release and static stretching. The y axis displays the stiffness in Nm°-1. The x axis displays the time and angle in which hamstring stiffness was measured including the: i) terminal ROM at the beginning of 4 weeks ii) terminal ROM at the beginning of 4 weeks, evaluated after the 4 wk intervention iii) terminal ROM at the end of the 4 week intervention. * indicates P=0.064. ** indicates P<0.05.
198x130mm (300 x 300 DPI)

TABLE 1. Participant Characteristics

Subjects (n)	19
Age (y)	20 ± 1
Height (m)	1.8 ± 0.01
Mass (kg)	78.7 ± 2.8
BMI (kg/m^2)	24.8 ± 0.9

Values are displayed as mean ± SE.

TABLE 2. Hamstring Stiffness

	SR		SMR+SR	
	Pre	Post	Pre	Post
Angle (°)				
110	0.46±0.03	0.40±0.03	0.45±0.03	0.43±0.03
120	0.43±0.03	0.42±0.03	0.46±0.03	0.45±0.03
130	0.44±0.04	0.44±0.04	0.49±0.03	0.49±0.04
140	0.50±0.05	0.49±0.05	0.54±0.05	0.54±0.05
150	0.63±0.08	0.57±0.07	0.63±0.08	0.62±0.06
160	0.83±0.11	0.72±0.10	0.76±0.11	0.75±0.09
170	1.06±0.16	1.21±0.16	0.95±0.15	1.35±0.13
Maximal pre-intervention angle	1.58±0.20	1.31±0.16*	1.27±0.19	1.17±0.15*

Stiffness pre and post every 10 degrees for both SR and SMR+SR groups in Nm.degree^{-1}. Values are mean ± SE. * Significantly different from pre (P<0.05).

TABLE 3. Muscle function

	MVC (Nm)		RTD (Nm/s)		Peak Passive Torque (Nm)	
Group	Pre	Post*	Pre	Post*	Pre	Post*
S	138.7±5.8	144.1±67.0	566.5±46.0	625.7±57.2	47.4±3.4	55.1±4.6
SR	144.7±7.7	147.0±7.5	621.9±59.4	652.8±63.7	47.3±3.2	52.8±4.6

Maximum voluntary contraction (MVC), rate of torque development (RTD), and peak passive torque. Values displayed as mean ± SE. * Significantly different from pre ($P<0.05$).