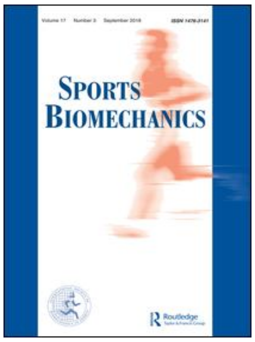

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Different volumes and intensities of static stretching affect the range of motion and muscle force output in well-trained subjects

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ABSTRACT

The manipulation of the volume and intensity of static stretching (SS) can affect the range of motion (ROM) and muscle force output. The purpose of this study was to investigate the effect of two different SS protocols with different intensities (50% and 85% POD) and volumes (120-s and 240-s) on ROM, peak force, and muscle activity during maximal isometric leg curl exercise in well-trained participants. Fifteen young males (age:27.5 ± 6.1years, height:175.6 ± 4.7cm, and body mass:81.5 ± 10.4kg, 6 ± 2 years of resistance training experience) performed passive hip flexion with two different SS protocols: six stretches of 40-s, with 15-sec rest between each stretch at 50% of the point of discomfort (POD) and three stretches of 40-s, with 15-sec rest between each stretch at 85%POD. The passive hip flexion ROM, biceps femoris muscle activation (integrated electromyography: IEMG), and knee flexors force were monitored during a 3-s maximal voluntary isometric leg curl exercise. ROM increased between pre- and post-intervention for both SS protocols (50%POD: $p = 0.016$, Δ% = 4.6% and 85%POD: $p < 0.001$, Δ% = 11.42%). Peak force decreased between pre- and post-intervention only for 85%POD ($p = 0.004$, Δ% = 23.6%). There were no significant IEMG differences. In conclusion, both SS protocols increased ROM, however, the high-intensity and short-duration SS protocol decreased peak force.

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flexibility; strength; exercise

Introduction

Different static stretching (SS) characteristics such as intensity and volume might affect or modulate the acute neurological and mechanical responses, however, with conflicting results (Behm & Kibele, 2007; Freitas et al., 2015; Kataura et al., 2017; Young, Elias, & Power, 2006). Since stretching volume and intensity are not precisely, inversely proportional relationships, it is fundamental to understand the effect of various combinations of stretch volumes and intensities on range of motion (ROM) and performance. An examination of the combination of these variables within individual studies is sparse within the literature. It is not well

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established whether an increased stretch duration versus an increased stretch intensity provides greater benefits to ROM and muscle force or power. For example, examining the effect of intensity, Behm and Kibele (2007) applied four stretches for 30-s each with 30-s recovery for the quadriceps, hamstrings and plantar flexors at 100%, 75% and 50% of the point of discomfort (POD) or a control condition. All three stretching intensities adversely affected jump heights (4.6%, 5.7%, and 5.4%, respectively). Additionally, Kataura et al. (2017) applied 180-s SS of the hamstrings at 80%, 100%, and 120% of maximum tolerable intensity. Static passive torque decreased after all intensities; however, only at 100% and 120% did the ROM increase and isometric muscle force decreased. These results indicate that high intensities of SS were more effective for increasing ROM and decreasing passive stiffness and isometric muscle force. In terms of the volume effect, Young et al. (2006) applied different SS durations (1-, 2-, and 4-min) at 100% of pain threshold and 2-min of SS at 90% of pain threshold. Ankle ROM and drop jump test were conducted after each protocol. For ROM, there were no differences between protocols, however for muscle performance, 2- and 4-min of SS at 100% of pain threshold impaired muscle performance, with no effect for 2-min at 90% of pain threshold. Interestingly, Freitas et al. (2015) examined the relationship of SS protocols with different volumes and intensities (5sets x 180-s/30-s rest at 50% of pain threshold, 5sets x 135-s/30-s rest at 75% of pain threshold, and 5x 90-s/30-s rest at 100% of pain threshold). They observed increases in angle and passive peak torque outcomes only for the 5x90-s at 100% of pain threshold protocol, whereas the 5x180-s at 50% of pain threshold protocol decreased passive torque. They concluded that high SS volume may reduce the passive torque and high SS intensity may increase the maximum joint angle.

While there are a multitude of studies using various stretch volumes and intensities, the exploration of the relationship between these variables (volume and intensity) has not been extensively integrated within single studies. Thus, the purpose of the present study was to investigate the effect of two different SS protocols with different intensities (50% and 85% POD) and volumes (120-s and 240-s) on maximal passive ROM, peak force, and muscle activity during maximal isometric leg curl exercise in well-trained subjects. It was hypothesised that the high-intensity SS protocol would present an increase in passive ROM, and reduction in peak force, and muscle activation. Because stretching activities are often practised by athletes and fitness enthusiasts before and after their main activities, it is important to clarify its effects on physical performance and flexibility. Previous evidence suggests that longer duration of stretching, as well as higher intensities, may reduce power output and may increase joint angles (Behm, 2018; Behm, Blazevich, Kay, & McHugh, 2016; Behm & Chaouachi, 2011). In this way, it is important to test the combination of these two variables to understand the impact of both on ROM, muscle activation and peak force. The understanding of specific changes in ROM, muscle activity and peak force might help with rehabilitation programs and prescription of complex training such as strength training and flexibility.

Methods

Participants

The sample size was justified by a priori power analysis based on a pilot study where the maximal range of motion in four well-trained participants was assessed as the outcome measure with an effect size difference of 0.70, an alpha level of 0.05, and a power $(1 - \beta)$ of 0.80. Therefore, fifteen young, healthy, resistance-trained men (age: 27.5 ± 6.1 years, height: 175.6 ± 4.7 cm, and body mass: 81.5 ± 10.4 kg) were recruited to participate in the current study. They had 6 ± 2 years of resistance training experience (at least 3 times a week), with no previous surgery or history of injury with residual symptoms (pain) in the lower limbs or spine within the last year. All participants had experience with stretching protocols as a component of the warm-up. The Nove de Julho University research ethics committee approved this study (#2.527.071/2018), and all participants read and signed an approved informed consent document.

Procedures

This project was a randomised crossover design. Participants attended one laboratory session and refrained from performing lower body exercise other than activities of daily living for at least 48 hours prior to testing. Participants performed a general warm-up of lower body cycling for 5 min at a cadence of 70 rpm at 1 kilopond, and a familiarisation session with five bilateral leg curl submaximal voluntary isometric contractions at 90° of knee flexion with 30-s rest between trials.

Then, all participants lay prone on a leg curl machine (Leg Extension Machine, Riguetto, Brazil), and each lower limb was positioned with the lateral femoral condyle in alignment with the mechanical axis of the equipment and maximal dorsiflexion. A strap was placed across their pelvis and bench to minimise hip movement. The machine lever arm was connected perpendicularly to a load cell (EMG832C, EMG system Brazil, São José dos Campos, Brazil), which was interfaced with a computer for recording, sampling at 2kHz. All participants performed three unilateral knee flexion maximal voluntary isometric contractions (MVIC) against a locked leg curl machine for 5-s with a rest period of 15-sec between trials, before and after each SS protocol (50% POD and 85%POD). Both SS protocols were conducted within the same session with 60-min of rest between protocols. The SS protocols (50%POD and 85%POD) and lower limbs were randomised for each participant. They also received verbal encouragement during all trials, and all measurements were performed between 6 PM and 8 PM, by the same researcher.

Intervention

Static-Stretching (SS) Protocols

All participants laid supine on a mat, hands behind the head, and legs in full knee extension. Then, a researcher passively moved their leg into hip flexion and kept the knee in full extension to the maximal hip flexion ROM. This hip flexion position primarily stretched the hamstrings. The intensity of each SS protocol defined by a numerical scale for pain and discomfort (point of discomfort, POD), where 0 = no stretch discomfort at all and 100% = the maximum imaginable stretch discomfort. All participants were familiarised on POD scale. All participants performed two different SS protocols with different intensities (50% and 85% POD) and volumes (set x duration): 50%POD (six stretches of 40-sec at 50% POD, with 15-sec rest, total volume = 240-s), and 85%POD (three stretches of 40-sec at 85% POD, with 15-sec rest, total volume = 120-s). While the use of subjective stretch intensities makes it difficult to equate stretching workloads, the higher intensity stretch protocol (85%POD) was allocated a lower volume of stretching to provide some degree of balance in terms of the stressors placed on the muscle groups.

Measurements

Passive Range of Motion (ROM)

Participants adopted a supine position with knees fully extended, and the lumbar spine supported on a mat. A fleximeter (Sanny, Brazil) was placed on the leg, above the ankle joint, and the legs were placed together to set zero degrees on the fleximeter. Then, each participant performed three trials of the passive ROM for maximal hip flexion, with a rest period of 10-s between trials before and after each SS protocol. The maximal passive hip ROM value was considered with the fleximeter (sensitivity of 1°).

Peak Force

Peak force was measured by a load cell for 5-sec of each MVIC at 90° of knee flexion and maximal dorsiflexion. All data were analysed with a customised Matlab routine (MathWorks Inc., USA). The digitised data were low-pass filtered at 10 Hz using a fourth-order Butterworth filter with a zero lag. Then, the first and last second was removed from force to avoid body adjustments', and the maximal value was considered for further analysis.

Surface Electromyography (sEMG)

Participants' skin was prepared before placement of the sEMG electrodes. Hair at the site of electrode placement was shaved, abraded, and the skin was cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes were used which were 1-cm in diameter for each circular conductive area with 2-cm centre-to-centre spacing. These were placed on each lower limb over the longitudinal axes of the biceps femoris (BF) long head at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). A ground electrode was placed on the right patella. The sEMG signals of the BF was recorded by an EMG acquisition system (EMG630C, EMG system Brasil, São José dos Campos, Brazil) with a sampling rate of 2KHz 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 x 20, noise > 5 μV), and analog-to-digitally converted (12 bit). sEMG signals were collected during MVIC against a fixed leg curl exercise. All sEMG data were analysed with a customised Matlab routine (MathWorks Inc., USA). The digitised sEMG data were band-pass filtered at 20–400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time domain analysis, RMS (150ms moving window) was calculated for all trials. Then, the first second was removed from sEMG RMS to avoid body adjustments', and the following 3-s of each trial were integrated (IEMG).

Statistical analyses

The normality and homogeneity of variances within the data were confirmed with the Shapiro-Wilk and Levene's tests, respectively. Data were analysed with two-way repeated measures ANOVA with two SS protocols (50% and 85% POD) and two times (pre- and post-intervention) for all dependent variables (hip flexion ROM, knee flexion peak force, and biceps femoris IEMG). Post-hoc comparisons were performed with the *Bonferroni* test. Cohen's formula for effect size (d) was calculated, and the results were based on the following criteria: trivial (<0.2), small (0.2–0.6), moderate (>0.5–1.2), large (1.2–2.0), and very large (>2.0) effects. Reliability was calculated using intraclass correlation coefficients (ICC) pre- and post-intervention for all dependent variables, and it was operationalised using the following criteria: <0.40 poor; 0.40-<0.75 satisfactory; ≥0.75 excellent. An alpha of 5% was used to determine statistical significance.

Results

Reliability (ICC) and confidence intervals for passive hip flexion ROM, knee flexion peak force and biceps femoris activation (EMG) are illustrated in Table 1.

For hip flexion passive ROM (Figure 1a), there was no interaction between SS protocols and time (p = 0.773). There was no main effect for SS protocol (p = 0.257), however there was a significant (p < 0.001) main effect for time, with an increase in both SS protocols from pre- to post-intervention (50%POD: 98.5°±8.44 and 103.4°±9.2, respectively [p = 0.016, d = 0.55 (moderate), Δ% = 4.6%] and 85%POD: 96.9°±9.5 and 109.3°±8.4, respectively [p < 0.001, d = 1.33 (large), Δ% = 11.42%]).

For knee flexion peak force (Figure 1b), there was a significant (p < 0.001) interaction for SS protocol and time, from pre- to post-intervention only for 85%POD (mean ± SD: 41.0 ± 9.2 and 31.3 ± 4.8, respectively [p = 0.004, d = 1.37 (large), Δ% = 23.6%]). There was no main effect for SS protocol (p = 0.257), however there was a significant (p < 0.001) main effect for time, with a decrease in both SS protocols from pre- to post-intervention.

For biceps femoris IEMG (Figure 1c), there were no significant IEMG interaction differences SS protocols and time (p = 0.799): 50%POD (mean ± SD: 1259.25 ± 526.18μV.s and 1228.82 ± 727.94μV.s, respectively), and 85%POD (mean ± SD: 1054.29 ± 351.50μV.s and 1072.51 ± 385.34μV.s, respectively). There was not a significant (p = 0.129) main effect for SS protocol or time (p = 0.973).

Table 1. Reliability as assessed by intraclass correlation coefficients and confidence intervals (CI) for the selected measures. **Acronyms**: POD: point of discomfort, ROM: Range of motion, IEMG: integrated electromyography.

	Pre-intervention 50% POD	Post-intervention 50% POD	Pre-intervention 85% POD	Post-intervention 85% POD
Passive Hip Flexion ROM	0.92 CI:93.8–103.2	0.95 CI: 98.3–108.6	0.93 CI: 98.3–108.6	0.95 CI: 104.6–114.1
Knee Flexors Peak force	0.99 CI: 36.1–45.6	0.99 CI: 33.3–42.9	0.98 CI: 33.8–47.5	0.98 CI: 33.1–44.0
Biceps Femoris Activation (IEMG)	0.90 CI: 943.4–1607.5	0.91 CI: 823.1–1409.9	0.94 CI: 890.5–1383.9	0.73 CI: 840.6–1550.4

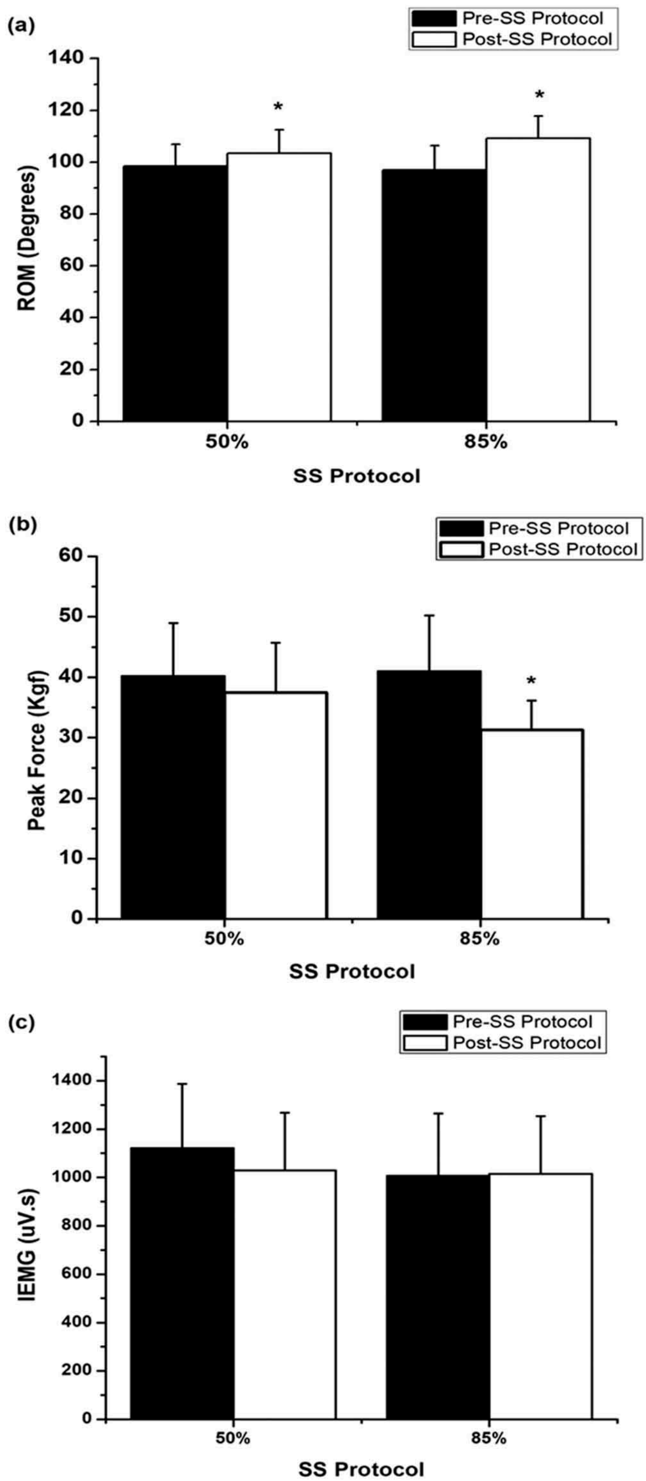

Figure 1. Mean ± standard deviation of (a) passive range of motion (ROM), (b) peak force, and (c) IEMG for pre- and post-SS protocols. *Significant difference between pre- and post-SS protocol, $p < 0.05$.

Discussion and implications

The purpose of the present study was to investigate the effect of two different SS-protocols with different combinations of intensities (50% and 85% POD) and volumes (240-s and 120-s) on maximal passive hip flexion ROM, knee flexion peak force, and biceps femoris (sEMG) activity during maximal isometric leg curl exercise in well-trained subjects. The main findings were that both SS protocols presented an increase in passive ROM but a reduction in peak force was only evident with the 85%POD. The present results partially corroborated the main hypothesis that high-intensity SS protocol would present a greater reduction in peak force (23.6%).

Acute increases in passive ROM after SS protocols are well documented in scientific literature (Behm et al., 2016; Behm, Buttom, & Butt, 2001; Behm & Chaouachi, 2011; Marchetti et al., 2015, 2017) and corroborated with the results of this study. The passive ROM increased after both SS protocols at 50%POD and 85%POD (4.6% and 11.4%, respectively). Although there was not a statistical difference between SS protocols, the high-intensity and short-duration (85%POD) protocol provided a large magnitude, 6.8% greater ROM when compared to the small magnitude effect size increase of the low-intensity and long-duration (50%POD).

Similar to the non-significant stretch intensity differences found in the present study, submaximal intensity (less than POD) stretches have provided similar ROM improvements as near-maximal or maximal POD stretches (Manoel, Harris-Love, Danoff, & Miller, 2008; Young et al., 2006). However the non-significant, but higher magnitude differences in favour of the 85%POD is similar to another study that reported SS at 85–100% of POD provided greater ROM than SS at 60% POD (Walter, Figoni, Andres, & Brown, 1996). It has been proposed that high force-short duration stretches emphasise temporary elastic tissue deformation, whereas low intensity, prolonged stretching enhances more plastic (semi-permanent) changes in tissue length (Sun et al., 1995). Behm (2018) suggests that SS to the POD could be counterproductive since a stiffening (co-contraction) strategy (Carpenter, Frank, & Silcher, 1999) is often adopted in response to pain or discomfort. Behm (2018) also contends that pain is highly subjective to the individual and thus telling a person with a high pain threshold to stretch to POD could place much greater stress on the tissues than for an individual with lower pain tolerance. Hence, if there are no significant differences in ROM between high and low POD, it may be safer (less chance for strain or sprain injuries) to stretch below POD (Behm, 2018).

The scientific literature regarding the effect of stretching intensity on subsequent performance is conflicting. Some research reports no impairments when SS was held to a point of mild discomfort (Lawrence & De Luca, 1983; Manoel et al., 2008), whereas others have demonstrated performance impairments with SS to a point of mild discomfort (Bradley, Olsen, & Portas, 2007; Hough, Ross, & Howatson, 2009). A significant reduction in knee flexion peak force was observed only after the 85% POD SS protocol (large effect size) corroborating similar studies with high-intensity protocols (Behm & Chaouachi, 2011; Bradley et al., 2007; Marchetti et al., 2015, 2017; Matsuo et al., 2013; Matsuo, Suzuki, Iwata, Hatano, & Nosaka, 2015). However, the SS-induced impulse deficit with high versus lower intensity SS contradicts Kibele and Behm and Kibele (2007), who found jump height was adversely affected by all experimental conditions, whether participants stretched the quadriceps, hamstrings and plantar flexors at 100%, 75% or 50% of POD (3 repetitions of 30 seconds each).

Thus in the present study, higher intensity SS would have placed greater tensile stresses upon the musculotendinous unit (MTU). This higher MTU tension at 85%POD could have contributed to the significant reduction in peak force due to factors associated with central drive inhibition or reduced contractile capacity (Trajano, Nosaka, Seitz, & Blazevich, 2014; Trajano, Seitz, Nosaka, & Blazevich, 2013). The SS stimulus may affect subcutaneous afferents (Corden, Lippold, Buchanan, & Norrington, 2000), group III and IV afferent receptors (Amann et al., 2013), reduce the discharge frequency from Ia afferents (Gandevia, 2001; Marsden, Meadows, & Merton, 1983). Acute SS has been suggested to reduce tendon stiffness, resulting in the MTU operating at shorter, and weaker (tension-length relationship) lengths (Cramer et al., 2007; Fowles, Sale, & MacDougall, 2000; Nelson, Allen, Cornwell, & Kokkonen, 2001; Weir, Tingley, & Elder, 2005). Unfortunately, exploring the mechanisms underlying the changes in the present study was beyond the scope of this paper and thus can only be speculated.

The maximal muscle activity (IEMG) was similar in both SS protocols and during pre- and post-intervention. The absence of differences may be explained by two main assumptions: 1. The angle-torque relationship was not affected in both SS protocols. 2. During maximal isometric contractions, the neural deficit imposed by SS protocols may be concurrent with the high level of neuronal outputs via the central nervous system to the muscle resulting in an absence of IEMG differences. Another important consideration is the non-linearity of the force-sEMG relationship, which is particularly prominent at the high force portion of the force-sEMG relationship (Lawrence & De Luca, 1983). Thus, the extent of sEMG activation deficits cannot be directly inferred as potential force deficits.

We recognise that this study has some limitations. We did not control for skinfold thickness of the sEMG detection area, that is considered to be a low-pass filter, and there may have been some inherent differences in the musculotendinous tightness between subjects. Repeating testing procedures on the same day may impact negatively any subsequent performance, however, in this study, we did not observe any residual effect from one condition to another. In this study, the application of the SS protocols did not focus on the knee/hamstring (supine position with fully extended knees and maximal hip flexion) when compared to maximum isometric knee flexion (lying on a leg curl machine), however, this was the best strategy to stretch the main muscle group (hamstrings). Additionally, different knee positions (i.e. 0º, 30º, 45º, 60º, and 90º degrees) could have been evaluated to add more information about changes in force and muscle activity. We also used healthy, well-trained participants, and our results are not generalisable to other conditions, populations, or athletes.

Conclusion

The present findings suggest that both SS protocols increase ROM, however, only the high-intensity and short-duration SS protocol decreased peak force during leg curl exercise in well-trained subjects. Thus, with the lack of significant differences in ROM between SS protocols, less than %POD SS is recommended to acutely enhance ROM with less chance of incurring subsequent impulse impairments. In this way, the combination of these two variables (volume and intensity) are important to understanding specific changes in flexibility, muscle activity and force that might help coaches or physiotherapists in improving rehabilitation programs and prescription of complex training such as strength training/flexibility.

Disclosure statement

No potential conflict of interest was reported by the authors.

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