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Research article

Upper Limb Static-Stretching Protocol Decreases Maximal Concentric Jump Performance

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Abstract
The purpose of the present study was to evaluate the acute effects of an upper limb static-stretching (SS) protocol on the maximal concentric jump performance. We recruited 25 young healthy, male, resistance trained individuals (stretched group, n = 15 and control group, n = 10) in this study. The randomized between group experimental protocol consisted of a three trials of maximal concentric jump task, before and after a SS of the upper limb. Vertical ground reaction forces (vGRF) and surface electromyography (sEMG) of both gastrocnemius lateralis (GL) and vastus lateralis (VL) were acquired. An extensive SS was employed consisting of ten stretches of 30 seconds, with 15 seconds of rest, and 70-90% of the point of discomfort (POD). ANOVA (2x2) (group x condition) was used for shoulder joint range of motion (ROM), vGRF and sEMG. A significant interaction for passive ROM of the shoulder joint revealed significant increases between pre- and post-SS protocol ($p < 0.001$). A significant interaction demonstrated decreased peak force and an increased peak propulsion duration between pre- and post-stretching only for stretch group ($p = 0.021$, and $p = 0.024$, respectively. There was a significant main effect between groups (stretch and control) for peak force for control group ($p = 0.045$). Regarding sEMG variables, there were no significant differences between groups (control versus stretched) or condition (pre-stretching versus post-stretching) for the peak amplitude of RMS and IEMG for both muscles (VL and GL). In conclusion, an acute extensive SS can increase the shoulder ROM, and negatively affect both the propulsion duration and peak force of the maximal concentric jump, without providing significant changes in muscle activation.

Key words: Kinesiology, neuroscience, physiology, performance.

Introduction

The effect of static stretching (SS) on the neuromuscular system has been attributed to both central and peripheral mechanisms. These performance (force and power) reductions can originate from neurophysiological (i.e. mechanoreceptors of the skin, muscle and joint proprioception), hormonal, cellular (structural changes such as titin), or mechanical (i.e. stiffness, torque-length characteristics) factors (Avela et al., 2004; Behm et al., 2004; Behm and Chaouachi, 2011; Pacheco et al., 2011; Rubini et al., , 2007; Serpa et al., 2014; Wallmann et al., 2005), and in some studies, it might persist for over several hours post-stretch (Brandenburg et al., 2007; Fowles et al., 2000; Haddad et al., 2014; Power et al., 2004).

The majority of these studies focus on how a specific stretching protocol affects the exercised muscle(s). On the other hand, there is evidence that the contralateral untrained limb might be affected by the trained limb, known as cross-over effect (Farthing, 2009; Zhou, 2000). Several articles have reported cross-over effects for different exercise conditions such as fatigue (Doix et al., 2013; Marchetti and Uchida, 2011; Rattey et al., 2006; Regueme et al., 2007; Strang et al., 2009; Todd et al., 2003), and force/power (Carroll et al., 2006; Farthing et al., 2005; Lee and Carroll, 2007; Sariyildiz et al., 2011; Shima et al., 2002), however, few articles have examined the cross-over effect after SS routines (Lima et al., 2014; Nelson et al., 2012). Nelson, et al. (2012) analyzed 10-week stretching program (4 times for 30s, with 30s rest, 3 $d \cdot wk^{-1}$). The results indicated an increase in strength (1RM) and ROM for both legs (stretched and non-streched limb), where the strength gain of the non-stretched leg was 56% of the stretched leg. Lima et al. (2014) investigated the acute effects of unilateral ankle plantar flexors SS (6 sets of 45s/15s, 70-90% point of discomfort (POD)) on surface electromyography (sEMG) and the center of pressure (COP) during a single-leg balance task in both lower limbs. The results indicated no differences on non-stretched limb for all dependent variables when compared to stretched limb.

The investigation of cross-over effect is mainly limited to assessing how the stretching protocols of an ipsilateral muscle affects the performance of the contralateral homologous muscle. There is less research investigating possible non-localized effects of upper-body on lower-body performance or vice versa. This type of question addresses whether fatigue is specific to working muscles or is it more of a systemic response. Previous studies have shown evidence for the existence of neural coupling between upper and lower-limb neural networks which may modulate the muscle activation, reflexes and coordination of muscles (Huang and Ferris, 2004; 2009). Considering the neural coupling between upper and lower-limb, some articles have reported this effect for fatigue conditions (Kennedy et al., 2013; Takahashi et al., 2011). Halperin et al. (2014) in two separate papers reported that fatigued elbow flexors impaired force and activation of contralateral knee extensors while in the second paper, knee extension fatigue caused decrements in the ability to perform repeated maximal voluntary contractions of the

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elbow flexors. Neural coupling could be facilitated by group *III* and *IV* muscle afferents (Martin et al., 2008). This feedback loop from muscle afferents can provide an inhibitory effect to the central nervous system leading to systemic decrements in the central drive to exercised and non-exercised muscles (Martin et al., 2008). Gandevia (2001) provides extensive evidence of supraspinal inhibition concluding that muscle feedback concerning biochemical and force-generating status can impair cortical sites. Long loop reflexes from muscle spindle afferents (Marsden et al., 1983) as well as skin and subcutaneous afferents (Corden et al., 2000) can influence cortical activation of the exercised and non-exercised remote muscles (Kagamihara et al., 2003). Hence, it would be important to ascertain the non-local muscle effects of stretching the upper body on lower body performance.

However, there is no scientific evidence for acute stretching-induced crosover or non-local muscle fatigue effects. Therefore, the purpose of the present study was to evaluate the acute effects of an upper limb SS protocol on the maximal concentric jump performance. It was hypothesized that extensive upper body SS would impair lower body jump performance.

Methods

Subjects

Based on a statistical power analysis derived from the maximum jump height data from a pilot study, fifteen subjects would be necessary to achieve an alpha level of 0.05 and a power (1-β) of 0.80 (Eng, 2003). Therefore, we recruited 25 young healthy, resistance trained individuals (stretched group: 15 males, age: 23 ± 5 years, height: 1.78 ± 0.08 m, and weight: 74.4 ± 13kg and control group: 10 males, age: 22 ± 6 years, height: 1.79 ± 0.07 m, and weight: 74 ± 15kg) to participate in this study. Individuals who participated in this study had no previous surgery on both upper and lower extremities, no history of injury with residual symptoms (pain, “giving-away” sensations). All the participants signed an informed consent form after receiving instruction on the experimental protocol of the research. This study was approved by the University research ethics committee (#35/2014).

Procedures

Prior to the data collection, the subjects were asked to identify the preferred leg for kicking a ball, which was then considered the dominant leg (Maulder and Cronin, 2005), and all subjects were right-arm dominant based on their preferred arm to write. All subjects were right leg and arm dominant. The experimental protocol consisted of: (1) a brief sub-maximal jumping warm-up for 5 minutes (20 jumps, 4 jumps with a rest interval of 45 seconds); (2) concentric jump task familiarization; (3) a pre-stretching evaluation of the upper limb (passive ROM); (4) three trials of maximal concentric jump task; (3) shoulder joint SS protocol; (4) immediately post-stretching evaluation of the upper limb (passive ROM); and (5) three trials of maximal concentric jump task. The control group followed the same procedures as the stretched group, except for the shoulder joint SS protocol. The control group remained seated during the same time interval that the stretched group performed the stretching protocol. All measures were performed by the same researcher and at the same hour of the day, between 9 and 12 AM.

Concentric jumping task (CJ): The subjects initially stood on the force plate (Biomec410, EMG System do Brasil, São José dos Campos, Brazil) with knee flexed to 90°, with the hands placed on the hips. The participant then held the position for a 2-s period at which time they were instructed to jump as high and fast as possible. The subjects left the force plate with the knee and ankle fully extended and landed in a similarly extended position. The CJ eliminated any active prestretch of the musculature and thus only utilized a concentric contraction (Power et al., 2004). The subjects were allocated at least 10s rest between jumps. Vertical ground reaction forces (vGRF) and surface electromyography (sEMG) of both gastrocnemius lateralis (GL) and vastus lateralis (VL) were simultaneously acquired at 2000Hz.

Measures

Surface electromyography recording (sEMG): The participants’ skin was prepared before placement of the EMG electrodes. Hair at the site of electrode placement was shaved and the skin was cleaned with alcohol. Bipolar active disposable dual Ag/AgCl snap electrodes 1cm in diameter for each circular conductive area and 2cm center-to-center spacing were placed unilaterally (dominant lower limb) over the longitudinal axes of the GL and VL. For the GL, the electrodes were placed in the direction of the line between the head of the fibula and the heel and for VL at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella, according to the SENIAM/ISEKI protocol. The sEMG signals of the GLs of both lower limbs were recorded by an electromyographic acquisition system (EMG832C, EMG system Brasil, São José dos Campos, Brazil) with sampling rate of 2000 Hz using a commercially designed software program (DATAQ Instruments Hardware Manager, DATAQ Instruments, Inc., OH, USA). EMG 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). A ground electrode was placed on the right clavicle.

Shoulder Joint Range of Motion (ROM): Subjects adopted a supine position with knees bent, supporting the lumbar spine at the bench. The fleximeter was placed on the dominant arm, above the elbow, and the hands were placed together to set zero degrees of the fleximeter. Then, each subject performed a passive ROM for a horizontal abduction movement of the shoulder joint. The maximal passive shoulder ROM was evaluated before and after the SS protocol with a fleximeter, with a sensitivity of 1º (Sanny, Brazil).

Intervention

Static-stretching protocol (SS): The subjects remained seated on a chair, with the hands behind the head, arms raised above the shoulder joint. Then, a researcher moved both arms (shoulder joint), at the same time, passively, to

Table 1. **Mean (±standard deviation) of the peak amplitude of the root mean square (RMS) and integrated electromyography (IEMG) before and after the static stretching (SS) protocol for vastus lateralis (VL) and gastrocnemius lateralis (GL) and groups (control and stretched).**

Variable	Muscle	Control Group		Stretched Group	
		Pre- Intervention	Post- Intervention	Pre- Intervention	Post- Intervention
Peak RMS	VL	.91 (.37)	.87 (.18)	.94 (.22)	.99 (.25)
(Volts)	GL	.53 (.11)	.59 (.12)	.59 (.15)	.60 (.15)
IEMG	VL	780 (334)	746 (214)	787 (210)	842 (204)
(V.s)	GL	424 (110)	445 (92)	457 (111)	468 (118)

the maximal ROM of the horizontal abduction position, bringing the elbows back as far as possible. An extensive passive stretching protocol was employed consisting of ten stretches of 30 seconds, with 15 seconds of rest between each stretch (Behm et al., 2004). The intensity was 70-90% of the point of discomfort (POD), where 0="no stretch discomfort at all" and 100%="the maximum imaginable stretch discomfort" (Behm and Chaouachi, 2011; Behm and Kibele, 2007). The POD intensity was required from the subjects during all stretches and the ROM was readjusted at 70-90% POD as necessary. The SS protocol was applied and controlled (POD) by the same strength and conditioning researcher.

Data analysis

All the vGRF and sEMG data were analyzed only during the propulsive CJ phase (defined by vGRF) by a customized Matlab routine (MathWorks Inc., USA). Then, the mean of the three maximal jumps were calculated for each variable.

CJ performance analysis: For each CJ task, the vertical GRF data was filtered with a fourth-order 80Hz low-pass zero-lag Butterworth filter. We computed the following variables during the propulsive phase of the CJ: (a) propulsive time, (b) peak of force, (c) impulse (vGRF area).

sEMG analysis: The digitized sEMG data was first band-pass filtered at 20-400 Hz by using a fourth order Butterworth filter with a zero lag. For the time domain analysis, we calculated the peak of RMS, using a maximal value of the EMG RMS (150ms moving window) for each muscle, and each EMG RMS data was integrated (IEMG).

Statistical analyses

The normality and homogeneity of variances within the data were confirmed with the Shapiro-Wilk and Levene tests, respectively. A mixed model ANOVA (2x2) was used for all ROM, vGRF and sEMG variables, with factors being group (stretched and control) and repeated measures for condition (pre- and post-stretching). Post-hoc comparisons were performed with the *Bonferroni* test. Cohen's formula for effect size (ES) was calculated, and the results were based on the following criteria: <0.35 trivial effect; 0.35-0.80 small effect; 0.80-1.50 moderate effect; and >1.5 large effect, for recreationally trained according to Rhea (2004). Test-retest reliability (ICC) was calculated and ranged between 0.76 and 0.98 for all dependent variables. An alpha of 5% was used for all statistical tests.

Results

A significant interaction for passive ROM of the shoulder joint revealed significant increases between the measurements taken before and those taken after the SS protocol (mean±SD: 134.9 ± 12.4° to 141.9 ± 14.4°, $p < 0.001$, ES = 0.54, Δ% = 5.93%). There were no significant differences with pre- to post-SS measures for the control group (mean±SD: 135 ± 12° to 139 ± 14°, $p = 0.704$). There were no significant main effects between the groups for shoulder joint passive ROM.

Regarding sEMG variables, there were no significant differences between groups (control versus stretched) or condition (pre-stretching versus post-stretching) for the peak amplitude of RMS and IEMG for both muscles (VL and GL) (Table 1).

A significant interaction demonstrated a decrease for peak force (Figure 1a) and an increased peak propulsion duration (Figure 1b) between pre- and post-stretching

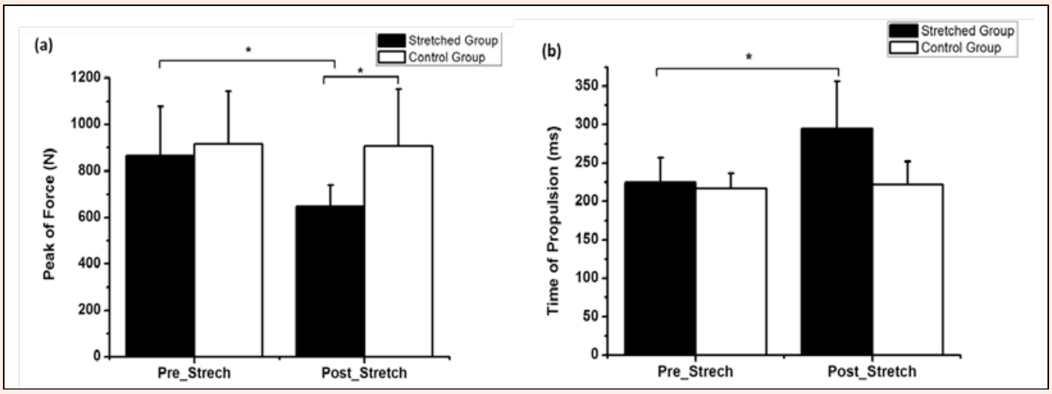

Figure 1. **Mean and standard deviation of the (a) peak of force and (b) time of propulsion before and after static stretching (SS) for both groups stretched and control.** * $p < 0.05$.

only for stretched group (p = 0.021, ES = 1.41, Δ% = 25% and p = 0.024, ES = 1.32, Δ%=23.6%, respectively). Additionally, there was a significant main effect between groups (stretched and control group) for peak force (p = 0.045, ES = 1.38, Δ% = 28.4%). For the impulse, there were no significant differences between pre-stretching and post-stretching for both stretched and control group.

Discussion

The purpose of the present study was to evaluate the acute effects of an upper limb SS protocol on the maximal concentric jump performance. It was hypothesized that extensive upper body SS would impair lower body jump performance.

The main findings of the present study were the evidence of impairment on the maximal concentric jump performance (increase of propulsion duration and decrease of peak force) and the increase of shoulder ROM after an acute upper limb SS protocol. The total volume (300s) and high intensity (70-90% POD) of SS used in the present study increased the passive shoulder joint ROM by 5.9%. However, the significant increases in shoulder joint passive ROM after the SS protocol only occurred with the stretched group.

Related to the force variables, we observed an increase of peak of propulsion phase and a decrease for peak force between pre- and post-stretching only for the stretched group. The non-local impairments associated with extensive upper body exercise on lower body performance is in accord with Halperin et al.(2014) who found a reduction in quadriceps muscle force and activation following a 100s isometric elbow flexor fatigue protocol. Similarly, Kennedy et al. (2013) reported 23% and 9% deficits in plantar flexors MVC after maximal and submaximal fatiguing protocols of the forearms. The decline in jumping performance of lower limbs after upper limb SS protocol suggests a central nervous system mechanism (Kennedy et al., 2013), taking into account the neural coupling between upper and lower-limb neural networks which might modulate the muscle activation, reflexes and coordination of muscles in a different extremity (Huang and Ferris, 2004; 2009). Halperin et al. (2014) detected a crossover fatigue effect from the fatigued elbow flexors and knee extensors to the non-exercised knee extensors but no significant effect on the non-exercised elbow flexors. They suggested the knee extensors were more susceptible than the elbow flexors to non-local or crossover muscle fatigue effects regardless of the muscle group being fatigued. It would be interesting in a subsequent investigation to examine whether the upper body to lower body SS deficits found in the present study would also occur with lower body SS influences upon upper body performance.

The effects of prolonged and intense SS on the joint receptors might lead to inhibitory inputs from afferent Type III (mechanoreceptor) and IV (nociceptor) afferents and Golgi tendon organ discharge, thereby limiting neural drive to the primary motor cortex. Long loop reflexes from muscle spindle afferents (Marsden et al., 1983) as well as skin and subcutaneous afferents (Corden et al., 2000) can influence cortical activation of the affected and non-local muscles (Kagamihara et al., 2003). Since intrafusal stretch receptor discharge frequency from Ia afferents can contribute up to 30% of the motoneuron excitation (Gandevia, 2001), SS-induced reductions in afferent excitability could adversely affect muscle force. As there is no horizontal connectivity within the primary motor cortex between arm and leg representations, the decline in supraspinal drive may be attributed to mechanisms that originate upstream of primary motor cortex, where arm and leg representations overlap considerably (Aboodarda et al., 2014; Byblow et al., 2007; Trajano et al., 2013). Gandevia (2001) provides extensive evidence of supraspinal inhibition indicating that muscle feedback concerning force-generating status can impair cortical sites.

Considering the sEMG variables, such as peak of EMG or IEMG, we did not observe significant differences between pre-stretching and post-stretching for both muscles (VL and GL) and groups. Perhaps this non-significant response can be explained by the non-linear force-EMG relationship (Solomonow et al., 1990). The earliest studies on the force-EMG relationship reported a linear relationship (Lippold, 1952) however; contemporary studies have illustrated a non-linear or curvilinear force-EMG relationships with the quadriceps during isometric (Alkner et al., 2000) and dynamic (Fujita et al., 2011) contractions. A non-linear force-EMG relationship indicates that the sEMG is not sensitive to all changes in force output, and it is not sensitive enough to capture the differences between conditions, which were relatively small (~5%). In addition, we can relate the high variability of the data (sEMG) with the inter-subject differences of the SS protocol intensity.

We recognize that this study has some limitations. The placement of the sEMG electrodes over the VL and GL might have led to cross-talk from adjacent muscles, such as the vastus intermedius, rectus femoris, soleus, tibialis, and peroneal muscles. We chose to use the most extensive SS protocol in the literature that included subjective information about the stretching intensity. However, we do recognize that the intensity of the stretching might not be commonly utilized during warm-ups to activity or during the rehabilitation processes.

Conclusion

In conclusion, an acute extensive SS protocol can increase the shoulder ROM, and negatively affect both the propulsion duration and peak force of the maximal concentric jump, without providing significant changes in muscle activation. These non-local effects should be taken into consideration by athletes, coaches, fitness professionals and rehabilitation specialists when stretching one body part and subsequently training another muscle. SS-induced deficits are not localized to only the stretched muscle and may affect subsequent power performance in other muscle groups.

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Key points

- The jump performance can be affected negatively by an intense extensive static-stretching protocol.
- An intense acute extensive SS protocol can affect positively the shoulder ROM.
- The intense acute extensive SS protocol does not change the level of muscle activation for vastus lateralis and gastrocnemius lateralis.

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