The effects of acute stretching on hamstring muscle fatigue and perceived exertion

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The aim of this study was to examine the effects of an acute stretching regime on hamstring muscle fatigue and rating of perceived exertion during a dynamic, sub-maximal bout of resistance exercise. Sixteen healthy males (age 25.7 ± 4.3 years, height 1.81 ± 0.06 m, body mass 87.5 ± 15.1 kg; mean ± s) and 16 healthy females (age 24.9 ± 4.5 years, height 1.67 ± 0.06 m, body mass 62.9 ± 9.4 kg) volunteered to participate in two experimental sessions. After establishing their one-repetition maximum for the hamstring curl, the participants were assigned at random to one of two groups. Group 1 performed three bouts of 20 s hamstring stretches with the assistance of one of the investigators, while group 2 did not perform the stretches; instead, they sat resting for 3 min. Then, after stretching or resting, the participants performed as many hamstring curls as they could at 60% of their one-repetition maximum established earlier. All participants were assessed for their perceived exertion using a modified Borg category ratio (CR-10) scale. The participants returned within 1 week to complete the experiment. This time group 1 did not perform hamstring stretches, whereas group 2 did. As on the first occasion, all participants performed hamstring curls after stretching or resting. The participants in group 1 were able to perform more curls on the second day of testing than their counterparts in group 2. There were no significant differences between males and females or between the stretch and non-stretch conditions. There was a significantly higher first repetition rating of perceived exertion for the stretch condition (2.88 ± 1.01) than for the non-stretch condition (2.50 ± 0.95); there was no significant difference in the median ratings of perceived exertion between the stretch and non-stretch conditions. Significantly higher power function exponents were exhibited in the non-stretch (0.57 ± 0.16) than in the stretch condition (0.51 ± 0.12). In addition, females exhibited significantly higher power function exponents than males, irrespective of stretch condition and day (females: 0.59 ± 0.12; males: 0.49 ± 0.11). In conclusion, we found a small but statistically significant effect of an acute bout of stretching on ratings of perceived exertion during fatiguing hamstring muscle resistance exercise.

Keywords: hamstrings, muscle fatigue, flexibility, perceived exertion.

Introduction

Muscle stretching regimes are routinely included in athletic and recreational fitness programmes in the belief that they prevent injury and improve performance. Recently, however, an accumulating body of literature suggests that performing a muscle stretching routine before resistance exercise reduces the performance of the quadriceps femoris and the plantar-flexor group (Kokkonen et al., 1998; Fowles et al., 2000; Nelson et al., 2001a,b). It has been hypothesized that the detrimental effect of muscle stretching on resistance exercise performance is mainly due to a reduction in muscle stiffness or increased compliance (Wilson et al., 1994). Most investigations have focused on measures of maximal muscle force generation, either through the measurement of isokinetic peak torque or a one-repetition maximum (1-RM); few studies have addressed the impact of acute muscle stretching on fatigue (Kokkonen et al., 2001).

The development of muscle fatigue is considered to go hand in hand with many different types of resistance exercises. It is well-established that physiological alterations that occur in human skeletal muscle as a function of fatigue, such as electromyographic and blood lactate changes, exhibit relationships with subjective measures of effort (Robertson and Noble,
Defined specifically as ‘perceived exertion’, this subjective estimate of physical effort during a sustained, fatigue-inducing contraction has displayed a plateau during isometric tasks (Hasson et al., 1989; Pincivero and Gear, 2000). A complex array of neurophysiological mechanisms that integrate centrally generated feedforward commands (Cafarelli, 1982) with peripherally mediated sensory signals arising from the contracting muscle (Thimm and Baum, 1987; Rotto and Kaufman, 1988) are thought to shape perceived exertion (Robertson and Noble, 1997). As previously suggested, an increase in muscle compliance, through acute stretching (Wilson et al., 1994), is the possible mechanism leading to decreases in force output. As a result, a transient elongation of the stretched muscle along the force–length curve, which functionally may place a given operating muscle length towards the ascending limb of this curve (Nelson et al., 2001a,b), may lower the magnitude of the afferent-generated signal to both spinal and higher somatosensory areas. A relative ‘muting’ of the sensory response may result and, therefore, be manifest in the rating of perceived exertion to a given muscle contraction. The impact of acute muscle stretching on fatigue and the corresponding estimate of subjective effort has received little attention (Kokkonen et al., 2001). The aim of this study was to examine the effects of an acute stretching regime on hamstring muscle fatigue and perceived exertion during a dynamic, sub-maximal bout of resistance exercise.

Methods and materials

Participants

Sixteen healthy males (age 25.7 ± 4.3 years, height 1.81 ± 0.06 m, body mass 87.5 ± 15.1 kg; mean ± s) and 16 healthy females (age 24.9 ± 4.5 years, height 1.67 ± 0.06 m, body mass 62.9 ± 9.4 kg) volunteered to participate in the study. The inclusion criteria were that the participants should be healthy and that they be aged 18–35 years. Individuals were excluded if they had any history of hamstring injury or a lower extremity injury in the previous 6 months, if they had exercised within 24 h of the test session or if they had any cardiopulmonary, neurological or systemic conditions. Before testing, all participants provided informed written consent and ethical approval was granted by the Institutional Review Board at Eastern Washington University.

Procedures

Each participant was required to perform two test sessions separated by 5–7 days. On the first day, the participants provided informed consent and were instructed on the procedures for the study. They completed a health history form (Physical Activities Readiness Questionnaire; American College of Sports Medicine, 2000) and their height and body mass were recorded. The participants were then assigned to one of two groups. Group 1 performed the stretch exercises in the first test session, whereas group 2 did not. In the second test session, group 2 performed the stretches and group 1 did not. Assignment to groups was counterbalanced. The stretching regime consisted of three bouts of 20 s hamstring stretches with the assistance of one of the investigators. Before each test session, the participants performed a 5 min sub-maximal warm-up on a cycle ergometer (Schwinn Co., Colorado). On the first test day, the participants were assessed for their one-repetition maximum on a prone hamstring curl machine (Biodex Medical Inc., Shirley, NY). After 10 min rest, they then performed another 5 min sub-maximal warm-up on the cycle ergometer. Immediately after this second warm-up, the participants did or did not perform stretches, depending on their grouping. If they did not stretch, they sat resting for 3 min. The participants subsequently performed as many hamstring curls as they could at a load equivalent to 60% of their one-repetition maximum and were then assessed for their perceived exertion. The procedures are summarized in Fig. 1.

<table>
<thead>
<tr>
<th>Group 1 (n=16)</th>
<th>Group 2 (n=16)</th>
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<tbody>
<tr>
<td><strong>Day 1</strong></td>
<td><strong>Day 2</strong></td>
</tr>
<tr>
<td>1-RM → Hs stretch</td>
<td>60% 1-RM</td>
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<tr>
<td>1-RM → No Hs stretch</td>
<td>60% 1-RM</td>
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Fig. 1. Group assignment and test order for the hamstring (Hs) stretch and non-stretch conditions.
Isotonic hamstring strength and endurance testing

During the first test session, the participants’ one-repetition maximum was established with them lying on the hamstring curl machine in a prone position with the hips flexed to approximately 20°. They were secured around the waist to the hamstring curl bench using Velcro straps to minimize movement during the exercise. The right leg was used regardless of leg dominance because the machine only allowed single leg testing with the right leg. A shield was fabricated and fixed to the weight stack to prevent the participants from knowing the amount of weight they lifted. This was done to remove the influence of this knowledge on the ratings of perceived exertion. The participants were then assessed for the maximum amount of weight that they could lift for one complete repetition (1-RM). A repetition was defined as the knee reaching approximately 100° flexion and returning to the start position (i.e. full knee extension). The average number of attempts required to establish the one-repetition maximum was four. A previous study had demonstrated a change of 12.5 ± 5.2% in knee extension 1-RM strength in healthy young women over two to five sessions of testing, with a correlation ($r^2$) of 0.94 (Ploutz-Snyder and Giamis, 2001).

After stretching or resting, the participants were repositioned on the hamstring curl machine and were instructed to perform as many hamstring curls as possible at a load equivalent to 60% of their one-repetition maximum. One investigator monitored each repetition so that the requested cadence of movement (approximately 3 s per repetition) was maintained, while another investigator recorded the number of repetitions. Strong verbal encouragement was provided to ensure that a maximum effort was given (McNair et al., 1996). The test was completed when a participant could no longer complete a full repetition. During the second test session, the participants performed hamstring curls with the identical 60% 1-RM mass used during the first session.

Hamstring stretch

The assisted hamstring stretch was administered by the same investigator. Each participant lay supine on a floor mat. The investigator secured the left leg of the participant to the mat by kneeling on a strap placed over the upper thigh. The investigator then passively flexed the participant’s right leg at the hip, keeping the knee in full extension. The leg was moved to a point where resistance was felt by the investigator; at this point the ankle was brought into dorsi-flexion. The stretch was confirmed verbally by the participant, and by palpation of the hamstring muscles by the investigator. The participant was instructed to relax as much as possible during the stretch. Each stretch was held for 20 s, followed by 10 s of relaxation. Three stretches were administered to each participant. Although we did not record the change in flexibility, a previous study found that a series of three unassisted and three assisted stretches held for 15 s each was sufficient to increase hamstring extensibility (Kokkonen et al., 1998).

Perceived exertion

Perceived exertion was assessed using the Borg category-ratio (CR-10) scale (Borg, 1982). Although this scale has been used to assess perceived exertion during strength training exercises, anchoring the perceptual range (described below) has been limited only to a few studies (Pincivero et al., 1999, 2000, 2001). A modification of the scale in the present study eliminated the numerical rating of 0.5 and changed the categorical ratings from ‘weak’ and ‘strong’ to ‘light’ and ‘hard’. Although the reciprocal change was originally made by Borg during development of the CR-10 scale (Borg, 1982), preliminary work suggested that during isolated muscle contractions, individuals were more able to appreciate these latter descriptors (Pincivero et al., 1999). To provide the participants in the present study with an understanding of a perceptual range, through which sensation intensities can be evaluated, one high and one low anchor was applied (Noble and Robertson, 1996). While laying prone on the hamstring curl machine before the establishment of their one-repetition maximum, each participant was asked to ‘think about’ how his or her right leg felt at that moment, in that position, and to think of those feelings as a zero. As the participants completed their 1-RM test, they were asked to ‘think about’ how their right leg felt and to think of those feelings as a maximum on the CR-10 scale. After 10 min rest and the second warm-up, the participants were instructed to perform two repetitions at 60% of their one-repetition maximum. During these two repetitions, they were asked to think about their exertion by observing the CR-10 scale, but were not asked to provide these ratings. These two repetitions were administered for familiarization purposes. After the stretches or 3 min rest, the participants returned to the hamstring curl machine as before and were asked to perform as many curls as possible using the 60% 1-RM load. After each repetition, the participants were asked to provide their rating of perceived exertion by selecting a number from the CR-10 scale. They were also told that they could provide a number higher than 10 if they so desired (Noble and Robertson, 1996).
**Data analysis**

The absolute mass lifted (kg) and the relative mass lifted [(total mass/body mass) × 100% = % body mass] were compared between males and females using unpaired t-tests. A three-way repeated-measures analysis of variance (stretch condition × day stretched × sex) was performed for the total repetitions completed during the 60% 1-RM trials for significant main effects and interactions.

A series of 3 three-way analyses of variance [stretch condition (2) × day stretched (2) × sex (2)] with repeated measures (on the day stretched factor) was performed on the first recorded perceived exertion value (following the first repetition) during the 60% 1-RM trial, the median perceived exertion value during the trial and the calculated power function exponents.

The power function exponents and perceived exertion linearity were examined by fitting the participant’s responses across the 60% 1-RM trial to the following power function: \( R = kS^n \), where \( k \) is the constant of proportionality, \( n \) is any real number, \( R \) is the perceived exertion response and \( S \) is the relative percentage across the exercise trial (Stewart *et al.*, 1998). The natural logarithm \( (\log_e) \) was calculated for the perceived exertion responses and the relative position across the 60% 1-RM trial (10–90% with 10% increments) for each participant, linearized on a log–log plot, and linear regression then applied to each participant’s data to estimate the slope and the constant, as given by the \( y \)-intercept \( (\log_e R = \log_e k + n\log_e S) \).

**Results**

**One-repetition maximum**

The results showed that males were able to lift a significantly greater absolute load than females (males 34.4 ± 7.0 kg, females 16.9 ± 3.1 kg; \( t_{30} = 9.13, P < 0.001 \)). In terms of relative lifting load, males exhibited significantly higher loads than females (males 39.3 ± 4.2%, females 27.0 ± 4.7%; \( t_{30} = 7.82, P < 0.001 \)).

**Repetitions to fatigue**

The results demonstrated a significant between-day main effect \( (F_{1,28} = 25.5, P < 0.001, \eta^2 = 0.48) \) and a moderate group × day interaction \( (F_{1,30} = 26.0, P < 0.001, \eta^2 = 0.46) \). This group × day interaction (Fig. 2) suggested that the participants who performed passive stretches on day 1 were able to perform significantly more curls on day 2 than the participants who did not stretch on day 1 (Table 1). There were no significant differences between the sexes in number of repetitions performed to fatigue.

**Perceived exertion**

We found a significant main effect for the first repetition rating of perceived exertion for stretch: rating of 2.9 ± 1.0 (mean ± s) for the stretch condition and 2.5 ± 1.0 for the non-stretch condition \( (F_{1,28} = 5.54, \ P < 0.01, \eta^2 = 0.17) \). There were no significant differences in the median ratings of perceived exertion between the stretch and non-stretch conditions. The predicted curves and the power function equations resulting from the log–log plot of the perceived exertion rating versus repetition number/total repetition (% total repetitions) are displayed in Fig. 2. The values of the power function exponents (<1.0), as well as the observable trend in Fig. 2, demonstrate that the perceived exertion response follows a negatively accelerating trend; the highest perceptual sensitivity appears to exist within the early phase of the exercise protocol. The results of the three-way analysis of variance demonstrated significant stretch \( (F_{1,28} = 5.48, \ P < 0.05, \eta^2 = 0.16) \) and sex \( (F_{1,28} = 5.84, \ P < 0.05, \eta^2 = 0.17) \) main effects for the calculated power function exponents. The non-stretch condition exhibited significantly higher power function exponents than the

![Graph](image)

**Fig. 2.** Number of hamstring curls to failure in the stretch and non-stretch conditions (mean ± s).

**Table 1.** Number of hamstring curls performed at 60% of one-repetition maximum for males \((n = 16)\) and females \((n = 16)\) assigned at random to group 1 (assisted stretch on day 1) and group 2 (assisted stretch on day 2) (mean ± s)

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<tr>
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<th>Day 1</th>
<th>Day 2</th>
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<tbody>
<tr>
<td><strong>Males</strong></td>
<td><strong>Females</strong></td>
<td><strong>Males</strong></td>
</tr>
<tr>
<td>Group 1</td>
<td>14.5 ± 3.0*</td>
<td>15.4 ± 1.8*</td>
</tr>
<tr>
<td>Group 2</td>
<td>15.9 ± 3.1</td>
<td>14.1 ± 1.9</td>
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*Significantly more repetitions performed on day 2 than day 1.
stretch condition (non-stretch: 0.57 ± 0.16; stretch: 0.51 ± 0.12) (Fig. 3). In addition, females were shown to exhibit significantly higher power function exponents than the males, irrespective of stretch condition and day (females: 0.59 ± 0.12; males: 0.49 ± 0.11). There were no significant interactions.

Discussion

In this study, an acute bout of stretching had a moderate effect on hamstring muscle fatigue during 60% 1-RM hamstring curls to failure. The participants who performed the stretching protocol on day 1 were able to complete more curls on day 2 than their counterparts in the other group. However, as both groups of participants experienced a significant increase in the number of repetitions on day 2 of the experiment, a learning effect may have been present. The presence of a stretching effect also appeared to be reflected in the first rating of perceived exertion (i.e. after the first repetition), as the muscle stretch condition resulted in a significantly higher rating than the non-stretch condition.

Hamstring muscle performance

A general reduction in maximal muscle force after muscle stretching has been observed (Kokkonen et al., 1998; Fowles et al., 2000; Behm et al., 2001). Kokkonen et al. (2001) examined muscle fatigue in 26 individuals who performed a single bout of resistance hamstring exercise at a load equivalent to 60% of individual body mass. After 20 min of hamstring and calf muscle stretching, the mean number of repetitions performed to failure was 12 ± 7, compared with 15 ± 7 repetitions in the ‘no stretch’ condition. The findings of the present study exhibited a similar trend, as the stretching routine may have compromised the number of repetitions performed. This was apparent for the participants who stretched on day 1, as they performed significantly more curls after the ‘no stretch’ protocol on day 2 than after acute stretching on day 1. However, that the other group also performed more repetitions on day 2 (the day on which they performed hamstring stretches) suggests the presence of a learning effect. It is conceivable, therefore, that the stretch routine on day 2 may have muted this learning effect, as suggested by the significant group x day interaction. Admittedly, the present study did not focus specifically on day-to-day variability in the number of repetitions performed at this particular load, in the absence of any intervention such as muscle stretching. Furthermore, it should also be noted that the present study sought to examine the effects of stretching on hamstring muscle performance, rather than determine the specific mechanisms involved in stretch-induced muscle force reduction.

The detrimental effects of muscle stretching on force development are evident during isometric (Kokkonen et al., 1998; Fowles et al., 2000; Behm et al., 2001; Nelson et al., 2001) and dynamic (Kokkonen et al., 2001; Nelson et al., 2001) contractions. After a series of thirteen 135 s passive stretches of the plantar-flexor muscles in 12 young volunteers, Fowles et al. (2000) observed a significant 28% decrease in isometric voluntary torque immediately after stretching, which remained depressed by 9% at 60 min. Based on the extrapolation method of Duchateau (1995), Fowles et al. (2000) concluded that impairments in motor unit activation accounted for 60% of the reduction in voluntary plantar-flexor torque immediately after stretching, with the remaining 40% being attributed to changes in mechanical muscle properties. Similar results were reported by Behm et al. (2001), who reported a 12.2% reduction in the isometric knee extension maximal voluntary contraction (MVC) 6–10 min after an acute 20 min stretching regime. This occurred simultaneously with alterations in muscle recruitment, as evidenced by a 20.2% decrease in rectus femoris electromyographic activity and an increase in the interpolated twitch torque during femoral nerve stimulation. Nelson et al. (2001) found that the inhibitory effect of acute muscle stretching on voluntary knee extensor torque was most evident at a relatively shorter muscle length (i.e. at an angle close to terminal knee extension). In terms of dynamic movement, Kokkonen et al. (1998) observed significant decreases in knee extension and flexion 1-RM of 8.1% and 7.3%, respectively, after five different lower
extremity stretching exercises. Nelson et al. (2001b) found that after three different stretching exercises of the quadriceps muscle, decreases in isokinetic knee extension peak torque of 7.2% and 4.5% occurred at 1.05 and 1.57 rad·s⁻¹, respectively, with no significant effects at higher velocities. It has been suggested that acute stretching induces an increase in muscle compliance (Rosenbaum and Hennig, 1995), thereby altering the force–length property of the muscle. At a given joint angle, therefore, the muscle would be operating closer to the ascending limb of the force–length curve (Fowles et al., 2000; Neslon et al., 2001a), which would require an increased amount of crimped muscle tissue to be lengthened during active tension development. Such a mechanism may help to explain why the stretch-induced decrease in muscle force production is primarily observed under isometric or low-speed movements. Nelson et al. (2001b) found no significant effects of muscle stretching on isokinetic knee extension peak torque at angular velocities of 2.62, 3.67 and 4.71 rad·s⁻¹. During counter-movement vertical jumps, Church et al. (2001) reported that the contract–relax proprioceptive neuromuscular facilitation (PNF) stretching technique of the lower extremities resulted in a statistically significant, yet small, decrease (mean reduction in vertical jump displacement = 1.47 cm, or 3.0%); the application of a static stretch of the same muscles resulted in no significant differences in vertical jump height. Similar results were reported by Knudson et al. (2001), who showed that 20 young volunteers experienced no significant changes in the following lower extremity kinematic variables during a counter-movement jump: peak vertical take-off velocity, duration of concentric and eccentric phases before take-off and knee angle. Applying the equations of constant acceleration (Mulligan, 1985; Hamill and Knutzen, 1995) to the data of Knudson et al. (2001), the peak vertical jump displacement averaged 35.48 cm for the no stretch condition and 34.64 cm for the stretch condition (mean difference = 0.84 cm, or 2.4%). Activities such as the vertical jump require the coordinated activation of many muscles in the lower extremity, which may explain the small effects of muscle stretching on this task. It may, therefore, be deduced that the detrimental effects of stretching are amplified when activities involving only the isolated muscle that is stretched, such as during some resistance exercises, are employed.

**Perceived exertion**

The ratings of perceived exertion during resistance exercise or isolated muscle contractions have been observed to correspond closely to the contractile state of the muscle (Pincivero et al., 2000). Similarly, a linear response to an increase in contraction intensity during isokinetic knee extensions at 1.04 rad·s⁻¹ was demonstrated by Pincivero et al. (2001); however, they also concluded that their participants underestimated their contraction efforts, as gauged by the Borg CR-10 scale. The results of the present study appear to follow this trend of underestimation during dynamic contractions, as the first recorded rating of perceived exertion was slightly greater than '2'. We also observed that the non-stretch condition exhibited significantly higher power function exponents than the stretch condition, which may be a result of the lower initial perceived exertion rating in the non-stretch condition. Modelling ratings of perceived exertion using a power function may be the most appropriate way of measuring this subjective estimation across a continuum such as contraction intensity or exercise duration (Stevens and Cain, 1970; Cooper et al., 1979; Noble et al., 1983; Jackson and Dishman, 2000). The negatively accelerating trend in the present study suggests a plateau effect as more repetitions are performed, in line with the results of previous work (Stevens and Cain, 1970); such an occurrence may be attributed to the inherent ceiling effect of the CR-10 scale at the middle to late phases of the exercise bout (Robertson and Noble, 1997) and to the relatively greater changes in muscle recruitment that occur at the beginning of a sustained contraction (Pincivero and Gear, 2000).

As a result of the decrease in muscle force after acute muscle stretching, an increase in the rating of perceived exertion to the same absolute load would be expected. The present results suggest that this may be the case, as the first rating of perceived exertion was found to be significantly higher in the stretch condition than in the non-stretch condition. As perceived exertion is partly mediated by a peripherally generated feedback mechanism, through muscle and joint mechano- and chemosensitive receptors (Thimm and Baum, 1987; Rotto and Kaufman, 1988; Kandel et al., 1995), relative desensitization should occur after an increase in muscle compliance (Fowles et al., 2000). This was evident in previous studies documenting decreases in muscle reflex excitability after stretching (Rosenbaum and Hennig, 1995; Avela et al., 1999). However, when the muscle is placed in a functionally weakened state, as is the case after muscle stretching, an increase in neural drive must occur to achieve an equivalent force (Cafarelli, 1982). Although the participants in group 2 performed more curls after stretching on day 2 of the experiment (which was attributed to a learning effect), a statistical main effect was present, albeit small ($\eta^2 = 0.17$). The functional consequence of the present findings is that ratings of perceived exertion are indicative of the contractile state of the muscle, but due to the relatively small effect size may lack accuracy.
Conclusions

Muscle stretching is routinely performed before many physical fitness routines in the hope of preventing injury and facilitating exercise performance. In light of recent findings in the scientific literature, however, the immediate influence of muscle stretching on force generation appears to be detrimental. The results of the present study suggest that an acute regime of hamstring stretching leads to a significant reduction in the maximal number of repetitions performed with a submaximal load. This pattern also appeared to be reflected in the ratings of perceived exertion, as these were found to be higher after muscle stretching. Although the effects were found to be statistically significant, the magnitude of such effects was considered small; however, it should be noted that successful performance in some sports is often enhanced considerably (or adversely affected) by very small changes in physical ability. Further studies into the impact of muscle stretching on fatigue should consider the functional significance of these effects.

References


