Is There a Sex Difference in the Minimum Number of Static Stretch Repetitions That Should Be Recommended to Improve Flexibility?

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The purpose of the present study was to determine whether the minimum number of static stretch repetitions required to induce an increase in range of motion of the ankle joint and a decrease in passive torque of the muscle-tendon unit is different between men and women. Twelve men and 15 women participated in this study. Ankle range of motion and passive torque were measured during the passive dorsiflexion phase of ten 10-s static stretching repetitions. The stiffness of the muscle-tendon unit and stress relaxation were also determined. There was no significant sex difference in any parameter. Ankle range of motion was significantly higher after the first stretch, but thereafter further increases were not observed. Passive torque at submaximal ankle angles was significantly lower after the first stretch, and passive torque at maximal dorsiflexion angle was significantly higher after the first stretch, although further increases were not observed. There were no significant stretching-induced effects on stiffness and stress relaxation. These results indicate that there are no sex differences in the effects of ten 10-s repetitions on flexibility, but show that this protocol is sufficient to induce changes in ankle range of motion and passive torque. Therefore, coaches should prescribe the same short-duration static stretching protocol for both sexes of athlete.

Keywords: range of motion, stiffness, ankle joint, passive torque

1. Introduction

Static stretching (SS) is commonly performed to improve flexibility. Changes in flexibility after SS can be assessed using mechanical factors, such as stiffness of the muscle-tendon unit (MTU), and neural factors, such as stretch tolerance, in addition to joint range of motion (ROM). Many previous studies have reported that acute SS increases joint ROM and decreases passive torque (PT) and stiffness of muscles, tendons, and MTUs (Kubo et al., 2001; Mizuno et al., 2013a; Morse et al., 2008; Ryan et al., 2008). In addition, an improvement in stretch tolerance (tolerance to stretching-induced pain) has been reported after SS (Magnusson et al., 1996; Mizuno et al., 2013a). Recent studies have also determined the effect of SS on muscle hardness, using shear-wave ultrasound elastography and reported a reduction in muscle hardness after SS (Akagi and Takahashi, 2013; Nakamura et al., 2014). However, the duration of stretching performed in many of these previous studies was long (Akagi and Takahashi, 2013; Kubo et al., 2001; Mizuno et al., 2013a, b; Morse, 2011; Ryan et al., 2008), and therefore may be not practical. To increase flexibility, the American College of Sports Medicine recommends that the duration of SS should be 10-30 s (American College of Sports Medicine, 2017), and in reality many athletes include 10-20 s of holding time during SS (Ebben and Blackard, 2001; Ebben et al., 2004; Ebben et al., 2005; Simenz et al., 2005). Furthermore, recent review articles have stated that many studies involve more than 30 s of holding time (Behm et al., 2015; Ichihashi et al., 2014). Therefore, it would be useful to evaluate the effects of a short duration of SS on flexibility.

A few previous studies have determined the effects of a short duration of SS on flexibility (Kay and Blazevich, 2008; Matsuo et al., 2013). Matsuo et al. (2013) reported that 20 s SS of the hamstrings increased straight leg raise and reduced PT during the static hold phase of SS, although no significant
Sex Differences in the Change in Joint Flexibility

changes were observed in stiffness or PT during passive knee extension. Another previous study showed similar reductions in PT after 5, 15, 20, or 60 s of SS (Kay and Blazevich, 2008). However, only one study of the minimum number of SS repetitions required to maximally and immediately increase flexibility has been carried out. Boyce and Brosky Jr (2008) determined the effect of 10 repetitions of 15 s SS of the hamstrings on joint ROM and demonstrated that significant increases in ROM did not occur from the fifth repetition. However, joint ROM provides limited information about flexibility; therefore, it is important to systematically evaluate the minimum number of SS repetitions required to improve not only joint ROM, but also mechanical and neural factors.

It has not been definitively determined whether the effects of SS on flexibility differ between men and women, because the number of studies conducted has been limited. Several previous studies have reported differences in flexibility between men and women. Ciprian et al. (2012) revealed that hip ROM is greater in women than men. Other studies have shown that the stiffness of the MTU and muscle are greater in men than women (Gajdosik et al. 2006, Morse. 2011). In addition, sex differences have been reported in the change in flexibility induced by SS. Hoge et al. (2010), who studied the effect of 9 × 135 s SS of the plantar flexors found a significant increase in ROM in women, but not in men. Another study identified a significantly greater reduction in stiffness in women (Burgess et al. 2009), implying that women are likely to be more affected by SS than men. Therefore, I hypothesized that the minimum number of SS repetitions required to induce an increase in joint ROM in men and women would be different. To test this hypothesis, I determined the minimum number of SS repetitions required to induce an increase in joint ROM and a reduction in PT, in men and women, after repetitive short-duration SS.

2. Methods

2.1. Experimental design

The subjects visited the laboratory on two occasions separated by more than 24 h. The first visit was for familiarization and the second was for participation in the experiment. During the familiarization visit, each subject practiced passive dorsiflexion to minimize any potential learning effects and to familiarize themselves with the procedures. During the experimental visit, the subjects undertook 10 sets of SS for 10 s, and PT (involuntary resistive torque against passive dorsiflexion), and the ROM of the ankle joint, and electromyography (EMG) of the medial gastrocnemius (MG) and tibialis anterior (TA) muscles were performed.

2.2. Subjects

Twelve men (mean ± SD; age: 19 ± 1 years, height: 170.4 ± 5.5 cm, mass: 59.5 ± 7.0 kg) and 15 women (mean ± SD, age: 19 ± 1 years, height: 158.9 ± 5.1 cm, mass: 51.2 ± 3.9 kg) with no recent lower-limb injury or illness volunteered for this study. None were involved in any structured physical training regime. All the participants gave their written informed consent. This study was conducted according to the principles of the Declaration of Helsinki and approval was obtained from the Local Ethics Committee.

2.3. Procedures

2.3.1. Static stretching

To determine the minimum number of SS repetitions required to induce changes in ankle ROM and PT, each subject undertook 10 passive stretches of the right lower leg. The SS was performed using an approach similar to that described in previous studies (Mizuno et al., 2013a; Morse et al., 2008). Subjects were seated at an isokinetic machine (S-15177; TAKEI SCIENTIFIC INSTRUMENTS, Niigata, Japan) with their knee in full extension. The angle of the back of the seat was set at 75° to the floor. The footplate attached to the isokinetic machine was fixed securely to the right foot of each subject and passively dorsiflexed at a constant velocity of 1°/s from 30° of plantar flexion, up to the dorsiflexion angle that provoked the sensation of maximal stretch in the lower limb, when the subject stopped the dynamometer by activating the safety trigger. This position was then held for 10 s. Thereafter, the footplate was returned to the 30° of plantar flexion position. This stretching procedure was repeated 10 times without a rest. The maximal dorsiflexion angle was reassessed at each dorsiflexion. Throughout their stretching, subjects were requested to relax...
completely and not to offer any voluntary resistance. In this study, all reported ankle angles refer to the angle of the footplate, and the ankle angle was defined as 0° when the footplate was perpendicular to the floor. Dorsiflexion angles are defined as positive.

SS was divided into 2 phases, which consisted of a passive-dorsiflexion phase and a static holding phase. During the passive-dorsiflexion phase, PT at submaximal ankle angles, PT at maximal dorsiflexion angle, and the ankle ROM, were measured. Submaximal PT was determined every 4° during the final 13° (at 1°, 5°, 9°, and 13°), which were common to each stretching repetition (from 1 to 10 sets of SS) (Ryan et al., 2008). Using these values, the stiffness of the MTU was calculated as the slope of SS (Ryan et al., 2008). Using these values, the stiffness of the MTU was calculated as the slope of SS to the value measured 10 s after starting SS. The standard errors of measurement for ankle ROM and PT at maximal dorsiflexion angle were 1.3° and 1.4 Nm, respectively. In addition, there were no significant differences between test-retest measurements for ankle ROM (t = −0.011, P = 0.991) and PT at maximal dorsiflexion angle (t = 0.182, P = 0.857).

2.5. Statistical analyses

A two-way analysis of variance (ANOVA) (the number of stretch repetitions [sets 1 to 10] × sex [man or woman]) was used to analyze the ankle ROM and stress-relaxation. A three-way ANOVA (the number of stretch repetitions [sets 1 to 10] × angle [1°, 5°, 9°, or 13° during the final 13°, and end ROM] × sex [man or woman]) was used to analyze PT. A three-way ANOVA (the number of stretch repetitions [sets 1 to 10] × angle [1°, 5°, 9°, and 13° during the final 13°] × sex [man or woman]) was used to analyze the stiffness of the MTU. A three-way ANOVA (the number of stretch repetitions [sets 1 to 10] × portion [initial 10° or final 5°] × sex [man or woman]) was also used to analyze the MG and TA EMG amplitudes. When appropriate, follow-up analyses were performed using lower-order ANOVA and t-tests with Bonferroni corrections. Differences were considered statistically significant at P ≤ 0.05. Data are shown as the mean ± SE, unless otherwise stated.

3. Results

3.1. Ankle range of motion

There was no significant two-way interaction (P = 0.714, η² = 0.019) and no significant main effect of sex (P = 0.397, η² = 0.029), but a significant main effect was measured for the number of stretch repetitions (P < 0.001, η² = 0.197). The ankle ROM was higher at the second (P = 0.011, 95% confidence interval [CI]: 0.308-4.141), third (P = 0.001, 95%
CI: 0.954-5.168), fourth (P=0.002, 95% CI: 0.818-5.530), fifth (P=0.007, 95% CI: 0.562-5.973), sixth (P=0.027, 95% CI: 0.175-5.641), and tenth (P=0.049, 95% CI: 0.007-6.497) sets of SS compared with the first set, although no further increase was observed after the second set (Figure 1).

3.2. Passive torque

No significant three-way interaction among the number of stretch repetitions, angle, and sex (P = 0.744, \( \eta^2 = 0.018 \)), and no significant two-way interactions between the number of stretch repetitions and sex (P = 0.703, \( \eta^2 = 0.021 \)) or angle and sex (P = 0.273, \( \eta^2 = 0.050 \)), were detected for PT, but a significant two-way interaction between the number of stretch repetitions and angle (P = 0.001, \( \eta^2 = 0.183 \)) was identified. Post hoc testing revealed that PT at submaximal angles was lower at the second set or later compared with the first set, and PT at maximal dorsiflexion angle was higher at the second set or later compared with the first set (all P<0.05; Table 1). However, no further increase was observed compared with the second set.

3.3. Stress-relaxation

There were no significant two-way interactions (P = 0.352, \( \eta^2 = 0.043 \)) and no significant main effects of sex (P = 0.432, \( \eta^2 = 0.025 \)) or number of stretch repetitions (P = 0.536, \( \eta^2 = 0.030 \); Figure 2)

3.4. Stiffness of the muscle-tendon unit

No significant three-way interaction among the number of stretch repetitions, angle, and sex (P = 0.181, \( \eta^2 = 0.062 \)) and no significant two-way interactions between the number of stretch repetitions

<table>
<thead>
<tr>
<th>Set of stretch repetitions</th>
<th>Final 1°</th>
<th>Final 5°</th>
<th>Final 9°</th>
<th>Final 13°</th>
<th>Maximal dorsiflexion angle</th>
</tr>
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<tr>
<td>1  Men</td>
<td>5.4±0.8</td>
<td>7.1±1.0</td>
<td>9.2±1.3</td>
<td>11.9±1.6</td>
<td>12.8±1.7</td>
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<td>6.2±0.6</td>
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<td>4  Women</td>
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</tr>
<tr>
<td>8  Men</td>
<td>5.1±0.7</td>
<td>6.7±0.9</td>
<td>8.8±1.1</td>
<td>11.5±1.5</td>
<td>14.5±1.8</td>
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<tr>
<td>8  Women</td>
<td>4.7±0.4</td>
<td>5.9±0.5</td>
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<tr>
<td>10 Men</td>
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<td>6.7±0.9</td>
<td>8.7±1.2</td>
<td>11.4±1.5</td>
<td>15.2±2.2</td>
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<tr>
<td>10 Women</td>
<td>4.5±0.4</td>
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<td>7.2±0.6</td>
<td>9.3±0.7</td>
<td>12.8±1.1</td>
</tr>
</tbody>
</table>

Values represent mean ± SE.
and sex ($P=0.673, \eta^2_p=0.023$), the number of stretch repetitions and angle ($P=0.521, \eta^2_p=0.030$), or angle and sex ($P=0.239, \eta^2_p=0.055$), were detected for the stiffness of the MTU. In addition, no significant main effects were detected for the number of stretch repetitions ($P=0.145, \eta^2_p=0.065$) and sex ($P=0.077, \eta^2_p=0.120$), but a significant main effect was observed for angle ($P<0.001, \eta^2_p=0.829$). The stiffness of the MTU significantly increased at each angle (all $P<0.001$; Table 2).

3.5. Electromyography

No significant three-way interactions among the number of stretch repetitions, portion, and sex were measured by EMG in the MG or TA (MG: $P=0.400, \eta^2_p=0.029$; TA: $P=0.683, \eta^2_p=0.019$) and no two-way interactions for the number of stretch repetitions and portion (MG: $P=0.374, \eta^2_p=0.032$; TA: $P=0.434, \eta^2_p=0.035$), the number of stretch repetitions and sex (MG: $P=0.381, \eta^2_p=0.031$; TA: $P=0.190, \eta^2_p=0.062$), or portion and sex (MG: $P=0.600, \eta^2_p=0.011$; TA: $P=0.183, \eta^2_p=0.070$) were detected. In addition, no significant main effects were detected for the number of stretch repetitions (MG: $P=0.377, \eta^2_p=0.032$; TA: $P=0.483, \eta^2_p=0.031$), portion (MG: $P=0.173, \eta^2_p=0.073$; TA: $P=0.226, \eta^2_p=0.058$), or sex with regard to the TA ($P=0.246, \eta^2_p=0.053$), although a significant main effect was observed for sex with regard to the MG ($P=0.027, \eta^2_p=0.180$). EMG amplitude for the MG in women was higher than that of men ($P=0.027, 95\% \text{ CI: 0.000-0.005}$).

4. Discussion

The purpose of the present study was to determine the minimum number of SS repetitions re-

Figure 2 Stretching-induced changes in stress-relaxation. Data are expressed as means ± SE.

Table 2 Stiffness of the muscle-tendon unit (Nm/deg) during each set of repetitions.

<table>
<thead>
<tr>
<th>Set of stretch repetitions</th>
<th>Final 1°</th>
<th>Final 5°</th>
<th>Final 9°</th>
<th>Final 13°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Men</td>
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<td>0.60 ± 0.27</td>
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<tr>
<td></td>
<td>Women</td>
<td>0.25 ± 0.12</td>
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</tr>
<tr>
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<td>0.46 ± 0.20</td>
<td>0.59 ± 0.26</td>
</tr>
<tr>
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<td>4</td>
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<tr>
<td>7</td>
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</table>

Values represent mean ± SE.
required to induce an increase in ankle ROM and a decrease in PT in men and women after repetitive short-duration SS. The main findings were that significant stretch-induced changes in ankle ROM and PT reached their maxima after SS for 10 s, but no sex differences were observed in the minimum number of SS repetitions required to improve flexibility.

A significant increase in ankle ROM was observed after 10 s of SS, but further increases were not observed. A previous study reported significant increases in knee extension ROM in each of the first five repetitions of SS for 15 s, but there were no improvements during SS repetitions five through ten (Boyce and Brosky Jr, 2008). The present results imply that the minimum number of SS repetitions required to induce changes in flexibility of the plantar flexors is less than that for hamstrings. Although the present study cannot provide a clear explanation for the discrepancy in the minimum number of repetitions required in the two studies, it is possible that differences in the type of stretching and/or in the target muscle of the SS may be involved.

There were no sex differences in the changes in flexibility parameters after SS. These results are consistent with those of previous studies that showed no sex differences in stress-relaxation during SS for 60 s, the stiffness of the MTU after SS of 135 s × 9 sets, or the gain in hip ROM after 4 weeks of SS (Cipriani et al., 2012; Gajdosik et al., 2006; Hoge et al., 2010). However, some previous studies have shown that the effects of SS on flexibility are better for women than men (Burgess et al., 2009; Hoge et al., 2010). The study by Hoge et al. (2010) involved SS consisting of 135 s × 9 sets, which resulted in increases in ankle ROM and stretch tolerance in women, but not in men. In addition, Burgess et al. (2009) demonstrated that women show greater reductions in stiffness, hysteresis, and Young’s modulus in comparison to men after 5 min of SS. The explanation for the differences between these previous studies and the present study could relate to the duration of stretching, which was much shorter in the present study. A longer duration of stretching induces larger changes in PT, straight leg raise, stiffness, and stress-relaxation (Freitas and Mil-Homens, 2015; Matsuo et al., 2013). Therefore, the duration of stretching in the present study might not be sufficient to reveal sex differences in the gain in flexibility after SS.

Many previous studies have demonstrated the influence of sex on potential flexibility, but the present study showed no significant differences in potential flexibility between men and women. Other studies have also shown no sex difference in joint ROM and PT (Gajdosik et al., 2006; Morse, 2011). However, most previous studies have shown that joint ROM in women is greater than that in men (Cipriani et al., 2012; Davis et al., 2008; Marshall and Siegler, 2014; Miyamoto et al., 2018). In addition, the stiffness of muscles, tendons and MTUs was greater in men (Blackburn et al., 2004; Kubo et al., 2003; Morse, 2011). A few potential explanations have been proposed for these differences, which include fluctuations in hormone levels and discrepancies in muscle cross-sectional area or the viscoelastic properties of muscle (Hoge et al., 2010; Morse, 2011). Some previous studies have suggested the involvement of estrogen, which affects collagen synthesis and tissue behavior (Burgess et al., 2009; Kjær and Hansen, 2008; Morse, 2011). However, one recent study found no significant changes in ROM and muscle elasticity during the menstrual cycle (Miyamoto et al., 2018). Furthermore, sex differences have been shown during menses, when estradiol levels are lowest (Hoge et al., 2010). Thus, estrogen concentration might not fully explain the sex differences in potential flexibility. Therefore, further investigations are required regarding the potential differences in flexibility between men and women.

The results of the present study show that the increase identified in ankle ROM after SS was due to an increase in stretch tolerance. There were significant increases in PT at the maximal dorsiflexion angle in subsequent sets compared with the first set, whereas no significant change was observed in PT or the stiffness of the MTU at submaximal angles. These results indicate that the subjects had a greater pain threshold (higher stretch tolerance) after SS, although the mechanical factors associated with the MTU did not change. The mechanism underlying the altered stretch tolerance is not fully understood; however, it is possible that the sensorimotor cortex is involved (Mizuno T., 2017).

There were no changes in the stiffness of the MTU across the 10 sets of SS. Previous studies in which participants performed 5 min of SS of the MG reported significant reductions in the stiffness of the MTU (Mizuno et al., 2013a, 2013b; Morse et al., 2008). Thus, a longer duration of SS would be
needed to reduce stiffness. In contrast, Ryan et al. (2009) demonstrated that 1 min of SS (two 30 sec sets of SS) was required to decrease stiffness of MTU. The discrepancy between the previous study and the present study might imply that not only the total duration of SS, but also the duration of each set of SS, is important. However, further study is required to evaluate this possibility.

The present study had one significant limitation. Ankle dorsiflexion during SS took 30-50 sec, because the velocity of dorsiflexion was 1°/s to prevent induction of the stretch reflex and provoke the clear sensation of maximal stretch. However, the time between sets might have weakened the effects of repetitive stretches compared with shorter gaps.

The present investigation has led to the following conclusions: 1) Significant alterations of ankle ROM, PT, and stretch tolerance are observed after SS for 10 s. 2) No further increases in flexibility occur between the second and tenth sets of SS. 3) There are no sex differences in potential flexibility and SS-induced improvement in flexibility using this protocol. Thus, performing SS for 10 s is sufficient to induce significant changes in flexibility in both men and women.

References
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