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doi:10.1152/japplphysiol.01193.2004

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Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys

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Submitted 25 October 2004; accepted in final form 21 March 2005

Marginson, Vicky, Ann V. Rowlands, Nigel P. Gleeson, and Roger G. Eston. Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys. J Appl Physiol 99: 1174–1181, 2005—The purpose of this study was to compare symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys. Ten boys (9–10 yr) and 10 men (20–29 yr) completed two bouts of eight sets of 10 plyometric jumps, 2 wk apart. Perceived soreness (0–10, visual analog scale), isometric strength of the quadriceps at six knee flexion angles, and countermovement jump and squat jump height were assessed before and at 30 min, 24 h, 48 h, and 72 h after each bout. All variables followed the expected patterns of change in men, with soreness peaking at 24–48 h (5.8 ± 1.7) and decrements in muscle function peaking at 30 min after the first bout (73–85% of baseline scores). Symptoms remained for 72 h after the first bout in men. In boys, symptoms were much less severe and peaked at 30 min (visual analog scale = 2.1 ± 1.8, functional decrements 87–92% of baseline) and, with the exception of soreness, returned to baseline after 24 h. After the second bout of plyometric exercise, the level of soreness and decrements in countermovement jump, squat jump, and isometric strength were lower, although the effect was stronger in men, in all cases. The results of this study suggest that although children may experience symptoms of muscle damage after intensive plyometric exercise, they are much less severe. A prior bout of plyometric exercise also appears to provide children with some protection from soreness after a subsequent bout of plyometric exercise. Explanations for milder symptoms of exercise-induced muscle damage in children include greater flexibility leading to less overextension of sarcomeres during eccentric exercise, fewer fast-twitch muscle fibers, and greater and perhaps more varied habitual physical activity patterns.

repeated-bout effect; muscle function; children; flexibility; delayed-onset muscle soreness

STRENUIOUS, UNACCUSTOMED ECCENTRIC exercise leads to muscle damage in adults (2, 26, 27, 38, 40, 41). The plethora of symptoms resulting from exercise-induced muscle damage (EIMD), particularly that caused by eccentric muscle activity in adults, is well documented (e.g., for reviews see Refs. 2, 10, 14, 15, 44, among others). Symptoms include delayed-onset muscle soreness (27, 39), presence of intramuscular proteins in the blood (42), and prolonged decrements in muscle function as evidenced by reductions in strength (13, 16), power output (7, 47), range of motion (16), and rapid dynamic muscle function, such as jumping, rebounding, and intermittent maximal intensity exercise (8, 10, 51).

The symptoms associated with exercise-induced muscle damage are substantially reduced after a second bout of unaccustomed eccentric exercise (32, 38, 43, 46). This effect is commonly referred to as “the repeated-bout effect” and is attained even if the symptoms after the first bout are mild (6). Explanations for the apparent prophylactic effect of a prior bout of EIMD have been reviewed recently (31, 32).

There have been few studies on EIMD in children, and no study has examined the repeated-bout effect in this group. Webber et al. (52) reported no difference in soreness and creatine kinase (CK) activity in children and adults after a downhill run. Their study suggested that the severity of damage was similar after an initial bout of damaging exercise. In contrast, Soares et al. (49) reported that boys appeared to suffer less damage compared with young men after a weight training protocol, based on measurements of soreness, CK, and isometric strength. Duarte et al. (17) observed that symptoms of damage in boys increased when the duration of the eccentric contraction in a stepping protocol was doubled, although no adult group was included for comparison.

Theoretically, it may be expected that the severity of symptoms of exercise-induced muscle damage would be decreased in children. McHugh et al. (33) observed greater symptoms of damage (strength, tenderness, CK activity) in men and women who were classified as having greater levels of passive stiffness in the hamstring muscles, compared with those who were classified as “compliant.” It was suggested that the reduced amount of stretch in the noncontractile component of the muscle in the stiffer muscles resulted in greater overstretching of the sarcomeres during exercise and hence more damage. It is well documented that flexibility is correlated with muscle stiffness (22) and decreases with age (1). Marginson and Eston (30) have already observed that the extensibility (passive flexibility) of the quadriceps muscle is significantly greater in boys compared with men. The greater flexibility and extensibility of children’s muscle may explain why the torque-joint angle curve of the knee extensors is shifted slightly to the right of the corresponding adult curve. In other words, peak torque occurs at a higher joint angle (longer muscle length) in children than adults (30). This study also observed a significantly greater decrement in peak torque beyond the optimal peak joint angle in adults. Recently it has been shown in adults that this decrement in torque beyond the optimal angle for torque production in the knee extensors, measured before eccentric exercise, is predictive of strength loss and pain after a bout of eccentric exercise (34, 35). This further supports the hypothesis...
that the rightward shift of the children’s torque-joint angle curve relative to the adult curve may mean children are less susceptible to damage.

It may be hypothesized that, in exercising at a given joint angle, the increased compliance of the child’s muscle would lead to differences in sarcomere lengths and affect the relative force that is capable of being exerted at a given joint angle. One of the most prominent explanations for the extent of damage caused by eccentric contractions involves the overextension of sarcomeres that fail to return to their normal length on relaxation of the muscle (36, 37). This effect is exacerbated during eccentric contractions at long muscle length (9, 12, 48) and moderated by the initial passive stiffness of the muscle group (33). Some researchers have reported a shift in the length-tension relationship toward longer muscle lengths after eccentric contractions (5). This adaptation is believed to be due to a shortening of some sarcomeres as compensation for the overstretched and irreversibly damaged sarcomeres in series after eccentric exercise (37). Reduced sarcomere overextension in children’s muscle may lead to reduced levels of muscle damage resulting from eccentric contractions.

There is also evidence to suggest that fast-twitch fibers are particularly susceptible to exercise-induced muscle damage (19, 20, 25). Because children have a lower proportion of fast-twitch fibers (28), the symptoms of exercise-induced muscle damage in children may be expected to be milder than those reported by adults.

Therefore, we hypothesized that the severity of symptoms of exercise-induced muscle damage after an initial bout of plyometric exercise would be milder in boys than in men. As a consequence, we also hypothesized that the repeated-bout effect would be less evident in boys than in men.

METHODS

Participants

Ten boys [age (mean ± SD) 9.9 ± 0.3 yr, height 138.2 ± 5.4 cm, mass 32.2 ± 6.3 kg] and 10 men [age 22.2 ± 2.7 yr, height 183.5 ± 5 cm, mass 71.8 ± 6.3 kg] participated in this study. All participants gave written, informed consent. In the case of the children, parents or guardians gave written consent and children gave verbal assent to participate in this study. The study was approved by the North West Wales National Health Service Trust Ethics Committee. Before any participation in this study, all participants completed health questionnaires to screen for any potential health risk. Reports of any history of knee pain or injury would have led to exclusion from the study. At the onset of the study, participants attended the laboratory for a familiarization session. This session also served to obtain target values for strength and jump height that the participant was encouraged to exceed during all subsequent testing.

Procedure

After familiarization procedures, which took place 2–3 days before, all participants performed two bouts of damage-inducing exercise separated by a 2-wk break. Before each bout, each participant followed a standardized warm-up. This consisted of five submaximal and five maximal continuous jumps and a standardized stretch of the quadriceps muscles, whereby the foot was raised to the buttocks. After the warm-up, participants performed eight sets of 10 continuous maximal plyometric jumps. Participants stood with feet shoulder width apart and hands on hips. Assuming this posture, they were asked to jump as high as possible on each jump after a preparatory downward eccentric movement, to a knee bend of ~90°, which was performed as fast as possible. Verbal guidance and encouragement were given throughout by the experimenter (V. Marginson). Each set of 10 jumps was separated by a 1-min rest period, in which the participant was allowed to walk around. Measures of isometric strength, countermovement jump height, squat jump height, and soreness were taken before each damaging protocol and at 30 min, 24 h, 48 h, and 72 h after each of the two bouts of damaging exercise.

Passive extensibility of the hip flexors (hip extension with knee flexion). During the familiarization period, passive hip extension was measured. Participants were placed in the prone position on a portable treatment couch (Darley, Cornwall, UK). A restraining strap was placed across the pelvis, and a partner stabilized the hips to prevent any extraneous movement. A Leighton flexometer (Leighton, Spokane, WA) was attached 2 cm proximal to the lateral malleolus. The knee was flexed to 120° (0° = full extension) and splinted to lengthen the quadriceps muscle. The Leighton flexometer was then transferred to the lateral epicondyle of the femur. The experimenter placed one hand under the hip, to ensure that the hip was not lifting off the couch, and the other hand under the thigh, proximal to the knee. The participant was asked to relax while the experimenter lifted the participant’s thigh to extend the hip to its maximum range of motion. Maximum hip extension was indicated by the participant saying “stop” (Fig. 1). The mean of three trials was taken as the performance measure (23).

Plyometric exercise protocol for inducing muscle damage. Power output was assessed by use of an infrared jump system (Optojump, Microgate, Bolzano, Italy) interfaced with a Hi Grade AMD K2 366-mHz laptop computer. Participants stood between two infrared sensor bars to perform the eight sets of 10 plyometric jumps. A visual display showed power output in real time. Participants were asked to try to beat or maintain target values that were based on their maximal countermovement jump height. Power output was recorded for each of the eight sets of 10 jumps for both bouts using the following equation, adjusted to obtain absolute power output in watts (4):

\[
PO = BM \cdot \left[ \frac{g^2 \cdot \Sigma t_{flight} \cdot (\Sigma t_{flight} + \Sigma t_{contact})}{4 \cdot N_{jump} \cdot \Sigma t_{contact}} \right]
\]

where PO is absolute power output (W), BM is body mass, \( g \) is the acceleration of gravity (=9.8065 m/s²), \( t_{flight} \) is flight time (ms), \( t_{contact} \) is contact time (ms), and \( N_{jump} \) is number of jumps.

Torque-joint angle relationship and isometric strength. The torque-joint angle relationship associated with the knee joint extensor musculature was assessed before and 30 min after each bout of damage-inducing exercise on an isokinetic dynamometer (Kin Com, 500H...
Participants were tested in the seated position with arms folded across the chest. Wooden boards were placed between the participant and the back of the seat to ensure that the angle between the thigh and the torso was the same for all participants. The axis of rotation was aligned with the lateral condyle of the femur, and restraining straps were used at the hip, thigh, and chest to prevent any extraneous movement. The pad of the lever arm was positioned proximal to the malleolus. The dynamometer lever arm length and horizontal and vertical positions were recorded for each participant to ensure that the testing position was the same across all testing days. Participants were asked to perform two 3-s, maximal voluntary isometric contractions of the quadriceps, at six different joint angles [20, 40, 60, 80, 90, and 100° (0° = full extension)]. Participants had a 3-min recovery period between each of the six contractions at each joint angle within each set and a 5-min break between the first and second set of six contractions. The peak force for each 3-s contraction was recorded, and the mean of the two contractions at each joint angle was used as the performance measure (21). Each participant was encouraged to exceed the target values obtained in the familiarization period. Visual feedback, via a visual display unit, which displayed force in real time, was provided throughout all testing. The joint angle that elicited peak torque before bout 1 was then used to assess isometric strength at all other time points after both bouts of plyometric exercise.

**Jump height.** Jump height was assessed by the infrared jump system, which was also used to assess power output during the damage-inducing exercise. Jump height was assessed with (counter-movement jump) and without (squat jump) a rapid preparatory downward eccentric movement, which utilized the stretch-shortening cycle. Before the assessment of jump height, all participants received a standardized warm-up of five submaximal continuous jumps and five maximal continuous jumps, to minimize the risk of injury. Participants performed three maximal jumps, separated by a 1-min rest. Visual feedback via the VDU of the laptop computer was provided throughout all testing. Participants were encouraged to perform to their maximal capacity and to try to jump higher than their previous jump. The highest jump height was taken as the performance measure. Jump height was calculated using microgate optojump software (DOS version 3), which utilizes the Bosco et al. (4) method to calculate the height of rise in the center of gravity. The vertical take-off velocity (V) of the center of gravity is calculated by

\[ V = 0.5(t_{\text{air}} \times g) \]

where g is acceleration of gravity (9.81 m/s²) and \( t_{\text{air}} \) is flight time in seconds.

The height of the rise of the center of gravity can then be calculated as follows:

\[ \text{Height (m)} = \frac{V^2}{2g} \]

**Perceived muscle soreness.** Perceived muscle soreness was evaluated by use of an illustrated visual analog scale, with a sliding pointer, numbered from 0 to 10 on the reverse side facing the experimenter. Descriptors were on the side facing the participant. The words “my muscles don’t feel sore at all” corresponded with the number zero. At the other end of the scale the words “my muscles feel so sore that I don’t want to move them” corresponded with number 10. Participants stood in an upright position, with their legs shoulder width apart, and flexed their knees slowly to a 90° angle. They then moved the sliding pointer along the scale to indicate the sensation of soreness in their thigh.

**Statistical Analysis**

Descriptive data were calculated for all variables. For analysis, strength and jump data were expressed as a percentage of baseline values. The purpose of this was to account for individual and group differences. An independent t-test was used to compare hip extension between men and boys.

The power output (W) elicited by each group during the damage-inducing jumping exercise was calculated for each of the eight sets of 10 jumps, for bout 1 and bout 2. A three-factor mixed-model analysis of covariance, with repeated measures on bout (2) and set (8), was used to assess group differences across both bouts. Body mass was used as the covariate.

To address the question of whether boys suffered milder symptoms of muscle damage after a single plyometric exercise bout, a series of two-factor mixed-model ANOVAs, with repeated measures on time (5), were used. The symptoms examined were soreness, isometric strength at the optimal angle, squat jump, and countermovement jump. A three-factor mixed-model ANOVA, with repeated measures on angle and time, was used to assess group differences in the torque-joint angle relationship from predamage values and whether this curve shifted to the right after the first bout of damaging exercise.

To address the question of whether the repeated-bout effect was evident in each group, a series of two-factor ANOVAs, with repeated measures on bout (2) and time (5), was used for men and boys separately. The symptoms examined were soreness, isometric strength at the optimal angle, squat jump, and countermovement jump.

Where appropriate, the Greenhouse Geisser correction was used to account for violation of the assumption of sphericity in the ANOVA analyses. Post hoc Tukey’s tests, modified for mixed-model ANOVAs (50), were used to follow up significant results.

Correlational analyses were undertaken to assess whether there was a relationship between flexibility and the severity of symptoms of exercise-induced muscle damage. Correlations were computed separately for range of motion with soreness, isometric strength, counter-movement jump height, and squat jump height at 30 min, 24 h, 48 h, and 72 h postdamage. Boys and men were assessed separately to avoid confounding the analysis because boys are typically more flexible than men and experience less severe symptoms of muscle damage.

This resulted in 32 correlations (4 symptoms × 4 time points × 2 groups). To account for the increased risk of Type 1 error, the Bonferroni correction was used and alpha was reduced to 0.0016 (0.05/32). Alpha was set at 0.05, unless stated otherwise.

**RESULTS**

Descriptive statistics are presented in Table 1. Hip extension was significantly greater \((t_{18} = 4.52, P < 0.001)\) in boys than in men.

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistics</th>
<th>Boys ((n = 10))</th>
<th>Men ((n = 10))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline isometric strength, N</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td>97.4±40.5*</td>
<td>434.0±106.9</td>
</tr>
<tr>
<td>40°</td>
<td>251.8±71.8*</td>
<td>879.2±164.4</td>
</tr>
<tr>
<td>60°</td>
<td>427.1±40.8*</td>
<td>1,407.2±190.8</td>
</tr>
<tr>
<td>80°</td>
<td>601.1±186.3*</td>
<td>1,615.8±205.8</td>
</tr>
<tr>
<td>90°</td>
<td>623.5±193.8*</td>
<td>1,404.3±194.0</td>
</tr>
<tr>
<td>100°</td>
<td>591.7±171.9*</td>
<td>1,164.5±160.2</td>
</tr>
<tr>
<td><strong>Jump height, cm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Countermovement</td>
<td>23.0±3.2*</td>
<td>36.3±4.5</td>
</tr>
<tr>
<td>Squat</td>
<td>18.9±2.4*</td>
<td>30.1±3.4</td>
</tr>
<tr>
<td><strong>Baseline isometric strength, N</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal angle</td>
<td>636.4±130.1*</td>
<td>1,630.6±177.0</td>
</tr>
<tr>
<td>Jump height, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Countermovement</td>
<td>21.7±2.5*</td>
<td>35.6±4.6</td>
</tr>
<tr>
<td>Squat</td>
<td>19.2±2.4*</td>
<td>30.7±3.5</td>
</tr>
</tbody>
</table>

Values are means ± SD. *Significant difference between groups, \(P < 0.001\).
Power output during the plyometric exercise protocol. There were no interactions for power output or main effects for bout or set. However, there was a main effect for group ($F_{1,17} = 5.4$, $P < 0.05$) indicating that power output (adjusted for body mass) was higher in men than in boys (Fig. 2).

Symptoms of Exercise-Induced Muscle Damage

Comparison of symptoms of damage after one bout of damaging exercise in boys and men. There were group × time interactions for soreness ($F_{2.3, 42.0} = 17.0$, $P < 0.001$, Fig. 3), relative isometric strength ($F_{2.6, 42.8} = 4.9$, $P = 0.007$, Fig. 4), and relative squat jump height ($F_{2.6, 42.8} = 4.9$, $P = 0.007$, Figs. 5 and 6). Post hoc analysis showed that soreness was greater, and strength and jump height lower, in men than in boys 30 min postexercise and throughout the measurement period ($P < 0.05$). In men, all symptoms remained different from baseline at 30 min, 24 h, 48 h, and 72 h postexercise ($P < 0.05$). However, in boys, soreness was only elevated above baseline at 30 min and 24 h postexercise ($P < 0.05$), and strength and jump height were only lower than baseline 30 min postexercise ($P < 0.05$).

Torque-joint angle relationship.

There was no group × time interaction for relative countermovement jump height ($F_{4, 72} = 1.1$, $P = 0.349$, Figs. 5 and 6), but there were main effects for time ($F_{4, 72} = 14.4$, $P < 0.001$) and group ($F_{1, 18} = 5.4$, $P = 0.032$). Post hoc analysis showed that relative jump height was lower than baseline for the entire measurement period ($P < 0.05$) and was higher in boys than in men ($P < 0.05$).

Fig. 2. Comparison of power output (adjusted for body mass) in men and boys during the plyometric exercise protocol. Bouts were separated by 2 wk. Values are means ± SE. Main effect for group ($P < 0.05$).

Fig. 3. Comparison of soreness in men and boys after 2 bouts of plyometric exercise. Bouts were separated by 2 wk. Values are means ± SE. *Significant difference between groups in bout 1 ($P < 0.05$). †Significant difference across time within bout; ‡significant difference across bout, within time ($P < 0.05$).

Fig. 4. Comparison of relative isometric strength (percentage of baseline) for men and boys after 2 bouts of plyometric exercise. Bouts were separated by 2 wk. Values are means ± SE. *Significant difference between groups in bout 1 ($P < 0.05$). †Significant difference across time within bout; ‡significant difference across bout, within time ($P < 0.05$).
There was no main effect of time or interaction involving time, showing that the muscle damage did not result in any shift of the torque-joint angle curve in either group.

**Repeated-Bout Effect**

**Soreness.** In boys there was a trend for a bout × time interaction \((F_{1.9, 16.8} = 3.4, P = 0.06,\) Fig. 3). There were main effects for bout \((F_{1, 9} = 5.8, P = 0.039)\) and time \((F_{1.9, 17} = 16.1, P < 0.001)\). Soreness was greater after the first bout than the second bout, indicating a repeated-bout effect, and post hoc analysis showed that soreness was elevated 30 min postexercise, then returned to baseline \((P < 0.05)\).

In men, there was a bout × time interaction \((F_{1, 0.13.5} = 4.3, P = 0.037)\). Post hoc analysis showed a repeated-bout effect whereby soreness was greater after the first bout than the second bout 30 min, 24 h, 48 h, and 72 h postexercise \((P < 0.05)\). After bout 1, soreness increased 30 min postexercise and remained elevated for the entire measurement period. Soreness was elevated above baseline at 24 and 48 h after bout 2 \((P < 0.05)\).

**Isometric strength.** In boys there was no bout × time interaction \((F_{4, 36} = 0.9, P < 0.498,\) Fig. 4) or main effect for bout \((F_{1, 9} = 0.8, P = 0.402)\), indicating no repeated-bout effect, but there was a main effect for time \((F_{1, 36} = 9.1, P < 0.001)\). Post hoc analysis showed that strength decreased 30 min postexercise, then returned to baseline \((P < 0.05)\).

In men, there was a bout × time interaction \((F_{4, 36} = 2.9, P < 0.001,\) Fig. 4). Post hoc analysis showed a repeated-bout effect whereby strength decrement was lower after bout 2 than after bout 1 at 30 min, 24 h, 48 h, and 72 h postexercise \((P < 0.05)\). After bout 1, strength decreased at 30 min postexercise and remained below baseline for the entire measurement period. Strength decreased at 30 min after bout 2 but was returned to baseline by 72 h postexercise \((P < 0.05)\).

**Squat jump.** In boys, there was a bout × time interaction \((F_{4, 36} = 2.7, P = 0.048,\) Fig. 5). Post hoc analysis showed that jump height was higher after bout 1 than bout 2 at 48 h postexercise, but higher after bout 2 than bout 1 at 72 h \((P < 0.05)\). After both bouts, jump height decreased below baseline.
at 30 min postexercise, then returned to baseline (P < 0.05), not supporting a repeated-bout effect. In men, there was a bout × time interaction (F4, 36 = 6.5, P < 0.001). Post hoc analysis showed a repeated-bout effect whereby jump height was higher after bout 2 than bout 1 at 30 min, 24 h, 48 h, and 72 h postexercise (P < 0.05). After both bouts, jump height decreased below baseline at 30 min postexercise and remained depressed for the entire measurement period (P < 0.05).

**Fig. 7.** Comparison of maximal torque at specific joint angles before and after the first bout of plyometric exercise in men and boys. *Significant group difference (P < 0.05).

**Countermovement jump.** In boys, there was a trend for a bout × time interaction (F4, 36 = 2.4, P = 0.067, Fig. 5). There were main effects for bout (F1, 9 = 8.5, P = 0.017) and time (F4, 36 = 4.2, P = 0.003). Jump height was lower after bout 1 than after bout 2. However, across bouts, jump height decreased at 30 min postexercise, then returned to baseline by 24 h (P < 0.05), not supporting a repeated-bout effect. In men, there was no bout × time interaction (F4, 36 = 1.8, P = 0.154, Fig. 6). There were main effects for bout (F1, 9 = 7.6, P = 0.002) and time (F4, 36 = 20.4, P < 0.001). Jump height was lower after bout 1 than after bout 2, indicating a repeated-bout effect. Jump height decreased 30 min postexercise and remained below baseline for the entire measurement period (P < 0.05).

**Relationship between flexibility and symptoms of muscle damage.** No relationships between any symptoms of damage and hip extension were found in boys. In the men, soreness at 24 h was negatively related to hip extension (r = −0.86, P = 0.001), indicating that the greater the flexibility, the lower the perceived soreness. There was a trend for a relationship at 48 h (r = −0.72, P = 0.019) and 72 h (r = −0.69, P = 0.029), but these were not significant after the Bonferroni adjustment to alpha (0.05/32 = 0.0016). No other symptoms were related to flexibility.

**DISCUSSION**

Eccentric exercise resulted in less severe symptoms of exercise-induced muscle damage in boys than in men. This was true for perceived soreness and for measures of muscle function. A repeated-bout effect was evident for all symptoms examined in men, but only for soreness in boys. This may be due to the greater symptoms of damage evident in men after the first bout. There was no evidence of a rightward shift in the length-tension curve after damage, in either men or boys. It should be noted that the lack of evidence for a rightward shift in the length-tension curve does not mean a shift did not occur. The sample size was small (only 10 participants per group), limiting the power to detect such a shift. Furthermore, the only previous study to demonstrate a shift of the curve in the knee extensors (34) showed the effect at an angle of 110°. The present study assessed torque only up to 100°.

The results for the men confirm that the eccentric exercise protocol was sufficient to induce damage because the symptoms experienced were of a similar severity to those reported in the literature and showed the expected temporal pattern (8, 13, 27, 43). Furthermore, the repeated-bout effect, as demonstrated by reduced symptoms after the second bout of exercise, was evident. Therefore, we have confidence that the relatively mild symptoms experienced by the boys reflect group differences in the response to the exercise, as opposed to an exercise protocol that was not severe enough. Notably, all symptoms of damage peaked at 30 min after the first bout of exercise in boys and, with the exception of soreness, were back to baseline 24 h after exercise, supporting the findings of Soares et al. (49). Therefore, it is possible that decrements in muscle function may have been attributable to fatigue.

Previous research has reported that squat jump height is affected to a greater extent than countermovement jump height after EIMD in adults (8, 11). Similarly, in the present study the decrement in performance was greatest for the squat jump in men. The pattern of decline and recovery in squat and countermovement jump height in men concurs with previous findings after a single bout of eccentric exercise (8, 11). In boys, both jumps appeared to be affected to a similar extent after bout 1, although recovery was quicker for the squat jump. After the second bout of exercise, squat jump height did not deteriorate, and countermovement jump height decreased only slightly, in boys. In fact, the boys showed a trend for a supramaximal response in the countermovement jump after the second bout.

Because decreased muscle compliance has been linked with more severe symptoms of exercise-induced muscle damage (33), it was hypothesized that boys may experience milder symptoms owing to greater flexibility. The negative correlation between soreness and hip extension in men supports this hypothesis. No such relationship was present in boys, possibly because flexibility was consistently high among the boys and this homogeneity of performance capability may have tended to limit the extent of correlation, giving a ceiling effect. As expected, hip extension was greater in boys compared with men. This may have contributed to the difference in the length-tension curves, evidenced by greater relative strength in boys at long muscle lengths, as previously observed by Marginson and Eston (30) in a separate group of men and boys.

Muscle length is an important moderating factor in the amount of muscle damage that is sustained, with exercise at longer muscle lengths leading to greater damage (9, 11, 46, 48). Morgan’s (36) popping sarcomere theory predicts a greater disruption to sarcomeres when the muscle functions at longer lengths corresponding to the plateau or descending portions of the torque-joint angle curve. Two recent studies...
symptoms of exercise-induced muscle damage in boys compared with men. The speed of recovery from the exercise bouts exhibited by the boys supports the use of plyometric training methods in boys.

REFERENCES


