Adaptation to exercise-induced muscle damage

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SUMMARY
1. Serum creatine kinase (CK) and muscle soreness, common indicators of muscle damage, were assessed in 16 subjects after performance of two bouts of eccentric exercise spaced 7 days apart. The purpose was (1) to examine rapid muscle adaptation when the ipsilateral limb was exercised on the second bout and (2) to investigate possible central adaptations when the contralateral limb was exercised on the second bout.

2. The LSL group (n = 7) and the LOL group (n = 9) performed the exercise with the ipsilateral and the contralateral limb, respectively. Careful attention was paid to stabilization of the subject so that the contralateral limb was not active in isometric stabilization.

3. For the LSL group, a lower CK and soreness response was found on bout 2 compared with bout 1. For the LOL group, no significant difference in CK response and soreness was found between bout 1 and bout 2.

4. No repeat bout effect was found when the contralateral limb was exercised; therefore central adaptation from performance of the first exercise was minimal. Because a lower repeated bout effect was found after bout 2 using the ipsilateral limb, it was concluded that an experimental design using ipsilateral muscle groups should provide a good model to study rapid muscle adaptation to exercise damage.

Key words: eccentric exercise, muscle adaptation.

Abbreviations: CK, creatine kinase; LOL, leg—opposite leg; LSL, leg—same leg.

INTRODUCTION
Novel or unaccustomed exercise results in elevation of serum creatine kinase (CK) and the development of delayed onset muscle soreness [1–11], both indicators of muscle damage. Direct evidence of exercise-induced damage has been shown by histological and ultrastructural analysis of the fibres. Studies have found that exercise causes structural alterations in the fibres, especially Z-line streaming and disorganization of myofibrils [7, 12, 13].

It is commonly known that participation in exercise training reduces muscle soreness by producing an adaptation in muscles. Studies have corroborated this belief by showing that training produces a smaller serum CK response and less soreness after a given exercise [9, 14]. However, recent studies have shown that performance of only one bout of exercise can generate a substantial training effect or adaptation [4, 5]. Clarkson et al. [5] showed that the first bout of an isometric exercise produced a significantly larger CK elevation compared with a subsequent bout given 7 days later. Likewise, Byrnes et al. [4] reported that a single bout of downhill running had a prophylactic effect on the development of muscle soreness and increases in serum levels of CK and myoglobin after a second run given up to 6 weeks later. These studies suggest that some type of adaptation occurs in the exercising muscle after only one bout of exercise. Thus the repeated exercise bout design should provide a good model to study the mechanism of rapid muscle adaptation to damage.

However, Graves et al. [8] found a lower CK response after a second bout of exercise when the second exercise used a different muscle group than the first. This study questioned whether the repeated bout effect, with regard to serum CK changes, actually represents an adaptation in the exercising muscle. In the study by Graves et al. [8], the exercise regimen consisted of isometric contractions that require a considerable amount of stabilizing activity in muscles other than those directly involved in the exercise. When the second bout of exercise was performed, the muscles used for stabilization may have gained some adaptation from performance of the first exercise. Thus the true effect of a previous exercise on the change in serum CK activity might have been obscured by the activity of stabilizing muscles involved in both exercise regimens.

The present study was designed to evaluate muscle soreness and serum enzyme changes after repeating an exercise with the same limb (ipsilateral) and with the
contralateral limb where special attention has been given to the isolation of specific working muscles. To simulate a novel bout of exercise we used an eccentric exercise regimen involving the hamstring muscles.

METHODS

Sixteen untrained male students at the University of Massachusetts, Amherst, volunteered to participate in the study and signed an informed consent document in accordance with the University guidelines for the protection of human subjects. The mean (±SD) age, height and weight were 21.7 (±2.6) years, 175.5 (±5.6) cm and 69.2 (±5.4) kg, respectively. All subjects were instructed to refrain from unaccustomed exercise during the course of the study starting 48 h before the first exercise session. Criterion measures of soreness and CK were assessed before and at 10, 13.5, 17, 20.5, 24 and 48 h after a bout of eccentric exercise using one leg. These subjects were then placed in one of two exercise groups: leg-opposite leg (LOL) (n = 9) or leg-same leg (LSL) (n = 7). The LOL group exercised the same leg at both exercise sessions while the LOL group exercised the contralateral leg on the second session. Right and left limbs were balanced over subjects and across days.

The exercise bout consisted of six sets of 10 eccentric contractions of the hamstring muscle group. Each contraction lasted for 10 s with a 20 s inter-trial rest. The six sets were each separated by 1 min rest. The intensity of the contractions for both bouts was set at 100% of the subject's initial maximal concentric strength (one repetition maximum). In the case where the subject could not complete a bout, the weight was reduced. However, the average force produced during the exercise was not significantly different from bout 1 to bout 2. The average force (±SD) produced for the LOL group on bouts 1 and 2 were, respectively, 65.5 (±7.2) kg and 65.1 (±6.8) kg. The corresponding values for the LSL group were 67.1 (±11.9) kg and 66.9 (±11.0) kg.

The subject performed the exercise while lying prone on an exercise bench. A strap was attached around the hips to stabilize the subject so that the working leg was not significantly activated during the exercise. Careful visual inspection of each subject assured the investigators that the contralateral leg was not active in stabilization. Also, electromyograph activity was visually monitored in the contralateral limb (non-working limb) in a sub-sample of subjects to check that this stabilization procedure adequately minimized action of the non-working limb. Since only minimal electromyograph activity was noted, we were satisfied that the subjects could adequately be stabilized in our testing set up.

A cuff was attached to the ankle of the working leg and hooked up to a weight tray pulley system, which allowed for eccentric loading of the hamstring muscle group. The subject assumed the starting position by bending the knee to a 90° angle. The pulley system allowed the researcher to bring the weights to the starting position so that the subjects did not perform any loaded concentric exercise.

The subject lowered the weights at the rate of 9°/s controlled by a light signal.

Blood samples were drawn from the cubital vein in the forearm before and at 10, 13.5, 17, 20.5, 24 and 48 h post exercise. These sample times were selected on the basis that CK activity is assumed to peak 10–24 h post exercise [3–5, 11]. The samples were allowed to clot at room temperature, centrifuged and preserved at −20°C until analysis. CK activity was assayed according to Szasz et al. [15] using a Boehringer Mannheim test kit. Muscle soreness was rated according to a scale from 1 to 10, where 1 was no soreness, 5 was sore and 10 was very, very sore. For all criterion measures, a repeated measures analysis of variance was calculated to determine differences over sample times and between bouts.

RESULTS

Fig. 1 represents the CK values expressed as a ratio of baseline values for bouts 1 and 2 in the LOL and LSL groups. Since the baseline CK values differed, an analysis of variance with covariance for baseline values was calculated. For the LSL group, a significant difference between bouts (P < 0.01), a significant difference over sample times (P < 0.01) and a significant bouts by sample time interaction term (P < 0.05) was found. For the LOL group, there was no significant difference between bouts or the bouts by sample times interaction term. For the LSL group, the mean absolute increase (±SD) in CK activity was 327 m-units/ml (±167) for bout 1 and 163 m-units/ml (±86) for bout 2. For the LOL group, the corresponding values for bouts 1 and 2 were 218 m-units/ml (±173) and 159 m-units/ml (±59), respectively.

The perceived soreness data are presented in Fig. 2. For the LSL group a significant difference was found between bouts but the interaction term (bout by sample times) was not significant. These data indicate that lower soreness was found on bout 2 but the overall pattern of response over time was the same between bout 1 and 2. For the LOL group, there was no significant difference in the overall response between bout 1 and 2.

For the LOL or LSL group, neither the absolute nor the relative increase in CK on bout 1 correlated with that on bout 2. Thus there was no relationship between the magnitudes of the bout 1 and bout 2 response.

DISCUSSION

Repeating the eccentric exercise with the same limb resulted in a reduced CK and soreness response on the second bout. This reduced response has been found for isometric arm flexion [5], isometric knee extension [16] and downhill running [4]. Graves et al. [8] examined an arm flexion isometric exercise and a knee extension exercise balanced over bouts 1 and 2. Regardless of the muscle group involved in the exercise, the CK response on the second bout of exercise was lower than expected. One explanation for this finding was suggested to be a faster clearance of CK on the second bout [8].
An alternative hypothesis may be that since isometric exercise involves considerable muscle stabilization, the reduced CK response may result from stabilizing muscles involved in both exercise regimens. This hypothesis is consistent with the previous findings of increased serum CK activity after isometric exercise or after those exercises that include isometric stabilization [3]. The present study carefully controlled the amount of stabilizing muscle activity. Our results showed a non-significant difference between the contralateral limbs (bouts 1 and 2) for either CK or overall soreness. Thus from the results of this study for the LSL group and previous studies that have found a lower CK and soreness response when repeating an exercise bout with the same limb, we can most likely assume that the adaptation occurs in the exercising muscle.

The mechanism of the repeated bout effect is unclear. Armstrong [17] and Byrnes et al. [3] suggested that a pool of fragile or stress susceptible muscle fibres were lethally damaged and eliminated by the first bout of exercise. Injury to these stress susceptible fibres would result in a release of CK from the damaged tissues and a production of noxious stimuli leading to the sensation of pain, tenderness or soreness. The noxious stimuli, which could be products of the inflammatory response or release of endogenous chemicals, excite free nerve endings in the muscle. Lethal injuries from a first bout of exercise would result in a temporary reduction in the stress susceptible fibres so that performance of a second exercise would result in a reduced CK and soreness response.

Schwane & Armstrong [18] provide evidence that does not entirely support the stress susceptible fibre hypothesis. Rats performed an exercise that did not produce
increases in CK before performing a second exercise that ordinarily would produce changes in CK. They found that the second exercise showed a reduced response, the repeated bout effect. Thus the evidence suggests that performance of one exercise bout produces a rapid adaptation in muscle making the fibres more resistant to further injury.

Since no repeated bout effect was found when the contralateral limb was exercised, central adaptation from performance of the first exercise was minimal. Because a lower repeated bout effect was found after bout 2 using the ipsilateral limb, it was concluded that this experimental design should provide a good model to study muscle repair and adaptation to damage.

REFERENCES


