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Repeated Eccentric Exercise Bouts Do Not Exacerbate Muscle Damage and Repair

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ABSTRACT

This study examined whether performing repeated bouts of eccentric exercise 2 and 4 days after an initial damaging bout would exacerbate muscle damage. One arm performed 3 sets of 10 eccentric actions of the elbow flexors (ECC1) using a dumbbell set at 50% of the maximal isometric force at 90° (SINGLE). Two weeks later the same exercise was performed by the opposite arm with the exception that subsequent bouts were performed 2 (ECC2) and 4 (ECC3) days after ECC1 (REPEATED). In the REPEATED condition, maximal isometric force (MIF) decreased to the same level immediately after ECC1–3, and the decreases in range of motion (ROM) and increases in upper arm circumference immediately postexercise were similar among the bouts. However, no significant differences in changes in MIF, ROM, muscle soreness, and plasma creatine kinase activity were evident between the SINGLE and REPEATED conditions when excluding the changes immediately after ECC2 and ECC3. These results suggest that ECC2 and ECC3 did not exacerbate muscle damage or affect the recovery process.

Key Words: muscle soreness, isometric strength, plasma CK activity, range of motion, swelling, elbow flexors

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Introduction

Delayed-onset muscle soreness (DOMS) is an outcome of eccentric exercise in which muscles are lengthened while producing force, and is a reflection of muscle damage and inflammation (2, 3, 5, 19). DOMS often develops after resistance training, especially when the intensity and volume of training are increased, the order of exercise is changed, or a new training regimen is performed (1, 2, 5). It has been suggested that 3 training sessions per muscle group per week is a minimum frequency for gaining muscle size and strength (8). To achieve this training frequency, resistance training occasionally needs to be performed while muscles are still experiencing DOMS from a previous session. In general, if a soft tissue injury occurs, it is harmful for the tissue to receive a damaging stimulus again in the early recovery process (9, 21). However, this does not seem to be the case for eccentric exercise-induced muscle damage.

It has been well documented that a repeated bout of the same eccentric exercise within several weeks results in significantly less damage (10–12). This phenomenon is still observed when a second eccentric bout is performed before full recovery from damage induced by a first bout. Ebbeling and Clarkson (7) showed that performing a second eccentric exercise bout 6 days after the first did not exacerbate muscle damage even though the loss in strength and range of motion had not recovered and residual soreness was present. Previous studies (6, 13) also showed that performing repeated bouts of eccentric exercise 3 and 6 days after the first bout did not result in further damage or retard the recovery process. Within the first few days after muscle-damaging exercise, significant adaptation must occur to make the muscle more resistant to subsequent damaging bouts. It has been documented that treatment of soft tissue injury must include an initial 24–48-hour period of rest (21). It is possible that repeating the damaging exercise within 1–2 days after an initial eccentric exercise bout may exacerbate muscle damage, because muscle soreness peaks and minimal recovery of strength occurs in this period. Moreover, in practical situations incorporating 3 training sessions per week, exercise is generally performed every second day. However, no study has examined muscle damage and soreness induced in this situation.

Therefore, the purpose of this study was to examine whether performing repeated bouts of eccentric exercise 2 and 4 days after an initial eccentric bout would exacerbate muscle damage and retard repair.

Methods

Figure 1 summarizes the experimental design of this study. One arm of the subjects ($n = 9$) performed a

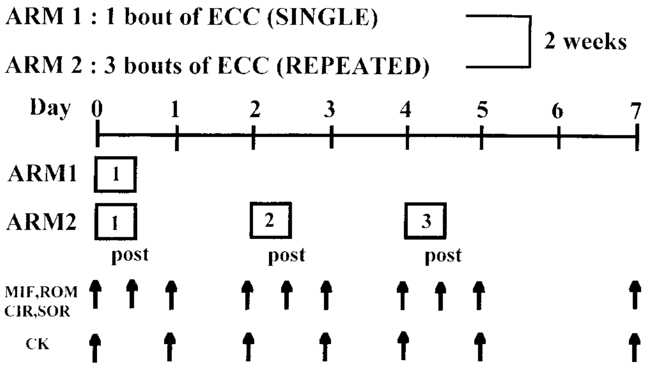

Figure 1. Experimental design and time course of the measurements. Post = immediately after exercise; MIF = maximal isometric force; ROM = range of motion; CIR = upper arm circumference; SOR = muscle soreness; CK = plasma CK activity.

single bout of eccentric exercise (ECC), and the other arm performed 3 bouts of ECC on days 0, 2, and 4. Changes in several indirect indicators of muscle damage reported in previous studies (5, 13, 14) were compared between arms to examine whether the repeated bouts of ECC performed 2 and 4 days after the initial bout would result in further changes or retard recovery of the indicators.

Subjects

Male students (n = 9) who had little or no experience in resistance training participated in this study after signing a written informed consent document consistent with ethical standards at Yokohama City University, which were in accordance with the Helsinki Declaration of 1975. Their mean (± *SD*) age, height, and weight was 19.2 ± 0.8 years, 171.6 ± 4.4 cm, and 66.4 ± 5.7 kg, respectively. There was no significant difference in the maximal isometric force (MIF) of the elbow flexors before exercise between the right (191.2 ± 12.9 N) and left (183.0 ± 19.5 N) arms. Subjects were requested not to perform any unaccustomed exercise or vigorous physical activities during the experimental period, and not to take anti-inflammatory drugs or nutritional supplements during the study.

Exercise

All subjects performed 3 sets of 10 repetitions of eccentric actions of the elbow flexors using a dumbbell that was set at 50% of each subject's MIF of the elbow flexors at an elbow angle of 90° (1.57 rad). For each eccentric action, subjects slowly lowered the dumbbell from an elbow-flexed (50°; 0.87 rad) to an elbow-extended position (180°; 3.14 rad) in 3 seconds. To perform only eccentric actions, the investigator removed the dumbbell at the elbow-extended position, and the subject returned the arm to the flexed position without external load. Each action was repeated every 15 seconds, and 3 minutes of rest was given between sets. The 50% load was chosen on the basis of the data of our previous study (unpublished data) showing that the load was nearly maximal for the untrained elbow flexors to perform slow eccentric actions at an elbow-extended position (>150°) in a controlled manner, but enough to induce muscle damage resulting in a prolonged force loss and range of motion (ROM), significant increases in plasma creatine kinase (CK) activity (>1,000 $IU \cdot L^{-1}$), and muscle soreness. As shown in Figure 1, one arm performed a single bout of this exercise (SINGLE) and 2 weeks later the contralateral arm performed the identical exercise followed by the same bout 2 and 4 days after the first (REPEATED). Dominant and nondominant arms were counterbalanced among subjects for the SINGLE and REPEATED conditions.

Criterion Measures

MIF of the elbow flexors, ROM of the elbow joint, circumference of the upper arm at the mid-belly of the biceps brachii (CIR), and muscle soreness (SOR) were assessed immediately before and after each exercise bout, and for 7 days after the first exercise bout except day 6 (Figure 1). Blood samples were taken before and 1–5 and 7 days after exercise, and plasma CK activity was determined (Figure 1). Reliability had been determined for these criterion measures by an intraclass correlation coefficient (R) before the present study. Reliability ranged from R = 0.91 (MIF) to R = 0.98 (SOR), with no significant day or trial effects in any measurements.

Maximal Isometric Force. MIF was measured twice for 3 seconds (1 minute between the measurements) by a load cell (model 1269, Takei Scientific Instruments Co. Ltd., Niigata, Japan) located between cables, and connected to a digital recorder at an elbow joint angle of 90° (1.57 rad). The mean value of the 2 measurements was used for the analyses.

Elbow Joint Angles and Range of Motion. Relaxed (RANG) and flexed elbow joint angles (FANG) were measured twice by a goniometer, and the angle, subtracting FANG from RANG, was used as the ROM.

Upper Arm Circumference. CIR was assessed at 3, 5, 7, 9, and 11 cm from the elbow joint by a tape measure while allowing the arm to hang down by the side, and the mean value of the 5 measurements was used for the analysis.

Muscle Soreness. A visual analog scale (VAS) that had a 50-mm line with "no pain" on one end (0) and "extremely painful" on the other end (50) evaluated muscle soreness upon palpation of the upper arm. Subjects were asked to mark their subjective scale of soreness on the line under the supervision of the examiner. The length of the line from 0 to the marked point provided a numerical measure of soreness. The VAS method has been established as a suitable method of assessing pain (16) and been used in previous studies (13, 14).

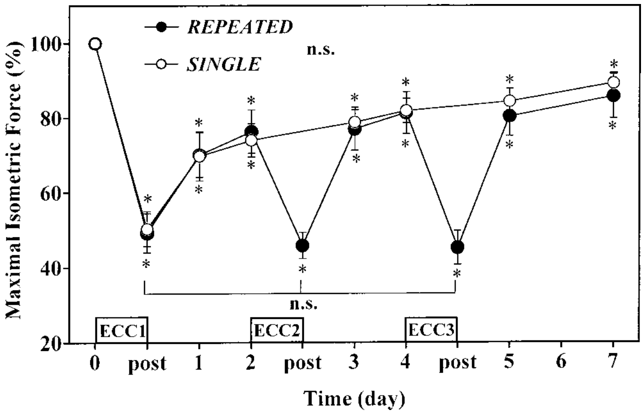

Figure 2. Changes in maximal isometric force from pre-exercise value (100%) after eccentric exercise in single-bout (SINGLE) and repeated-bout (REPEATED) conditions. * = significant ($p < 0.05$) difference from the pre-exercise level. Comparison between the conditions was made without the measurements taken immediately after second (ECC2) and third (ECC3) bout in the REPEATED condition. For the REPEATED condition, comparisons of the force level immediately after exercise between the bouts are also shown. n.s. = not significantly different.

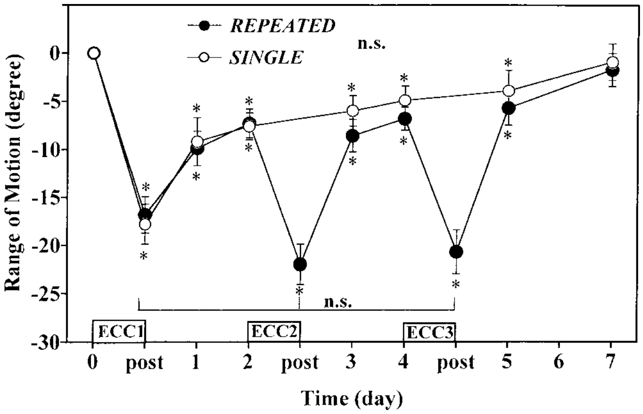

Figure 3. The amount of change in range of motion of the elbow joint angle (ROM) from pre-exercise value (0) after eccentric exercise in single-bout (SINGLE) and repeated-bout (REPEATED) conditions. * = significant ($p < 0.05$) difference from the pre-exercise level. Comparison between the conditions was made without the measurements taken immediately after second (ECC2) and third (ECC3) bout in the REPEATED condition. For the REPEATED condition, comparisons of the ROM immediately after exercise between the bouts are also shown. n.s. = not significantly different.

Plasma CK Activity. Approximately 5 ml of blood samples were taken from the antecubital vein by a standard venipuncture technique using lithium-coated tubes. Plasma CK activity was determined by VP-Super System (Dynabot Co. Ltd., Tokyo, Japan) using a test kit (Dynabot). The normal reference range of plasma CK activity for male adults by this method is 45–135 $IU \cdot L^{-1}$.

Statistical Analyses

The results were expressed as means ± *SEM*. Changes in all criterion measures with time were compared between SINGLE and REPEATED conditions using a two-way analysis of variance (ANOVA) with repeated measures; between-group factor was exercise mode (SINGLE vs. REPEATED) and within-group factor was time (pre-D7). When the ANOVA produced a significant main effect, a Tukey's honestly significant difference test was used to detect differences in the measures between the conditions at different time points. Changes in MIF, ROM, CIR, and muscle soreness from immediately before and after each exercise bout for the REPEATED condition were compared using a one-way ANOVA. The level of significance was set at $p \leq 0.05$.

Results

Maximal Isometric Force

MIF dropped to approximately 50% of the pre-exercise level immediately after the first exercise bout (ECC1), recovered to 70% at 1 day, and 75% at 2 days postexercise (Figure 2). Changes in MIF were not significantly different between SINGLE and REPEATED conditions over the 7 days after the first exercise bout when changes immediately after the subsequent bouts were excluded (Figure 2). At 7 days after ECC1, MIF was still significantly ($p < 0.05$) lower than the pre-exercise level for both conditions. In the REPEATED condition, the amount of decrease in MIF immediately postexercise in the second (ECC2) and third bouts (ECC3) was significantly ($p < 0.05$) smaller than that of ECC1. Although the pre-exercise MIF for bouts ECC2 (144 N) and ECC3 (154 N) were significantly ($p < 0.01$) lower than that of ECC1 (191 N), the MIF immediately after ECC2 (87 N) and ECC3 (86 N) was not significantly different from ECC1 (93 N) (Figure 2).

Range of Motion

ROM decreased 17–18° immediately after exercise and gradually recovered to the pre-exercise level by 7 days after ECC1 (Figure 3). Excluding the changes immediately after ECC2 and ECC3, the changes in ROM were not significantly different between SINGLE and REPEATED conditions over the 7 days after the first eccentric bout (Figure 3). In the REPEATED condition, ROM decreased significantly ($p < 0.05$) immediately after each bout; however, the amount of decrease in ROM (approximately 15°) was not significantly different between the bouts (Figure 3).

Circumference

The amount of increase in CIR was 8–10 mm immediately after exercise, but decreased to approximately 5 mm by 1 day and to 2 mm by 7 days after exercise for the SINGLE condition (Figure 4). The REPEATED condition showed significantly ($p < 0.05$) larger increases compared with the SINGLE condition after the

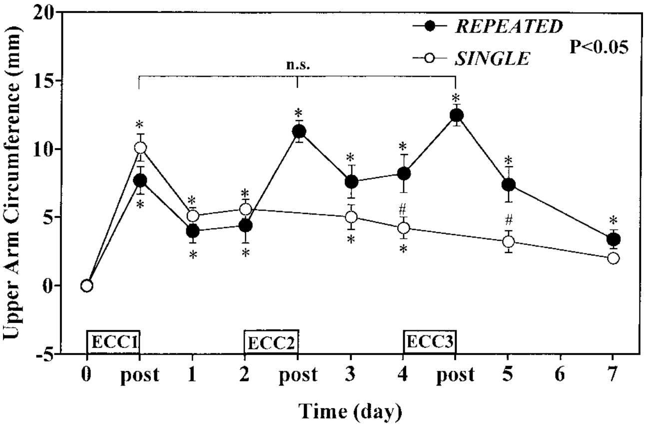

Figure 4. The amount of changes in upper arm circumference (CIR) from pre-exercise value (0) after eccentric exercise in single-bout (SINGLE) and repeated-bout (REPEATED) conditions. * = significant ($p < 0.05$) difference from the pre-exercise level. Comparison between the conditions was made without the measurements taken immediately after second (ECC2) and third (ECC3) bout in the REPEATED condition. # = s where a significant difference ($p < 0.05$) between the conditions was found. For the REPEATED condition, comparisons of the CIR immediately after exercise between the bouts are also shown. n.s. = not significantly different.

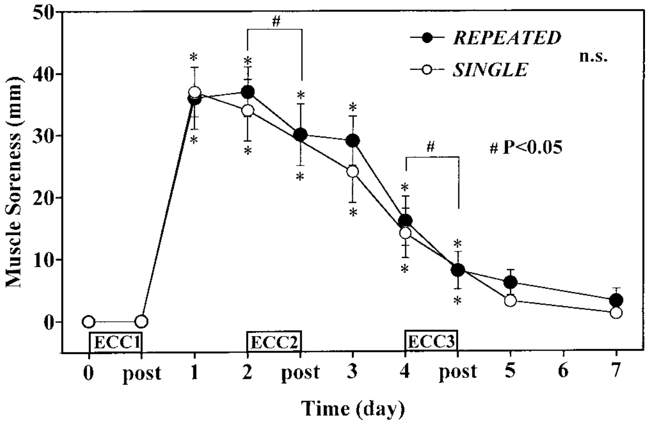

Figure 5. Changes in muscle soreness of the upper arm (SOR) after eccentric exercise in single-bout (SINGLE) and repeated-bout (REPEATED) conditions. * = significant ($p < 0.05$) difference from the pre-exercise level. Comparison between the conditions was made without the measurements taken immediately after second (ECC2) and third (ECC3) bout in the REPEATED condition. For the REPEATED condition, comparisons of the SOR between before and immediately after exercise are also shown. # = $p < 0.05$; n.s. = not significantly different.

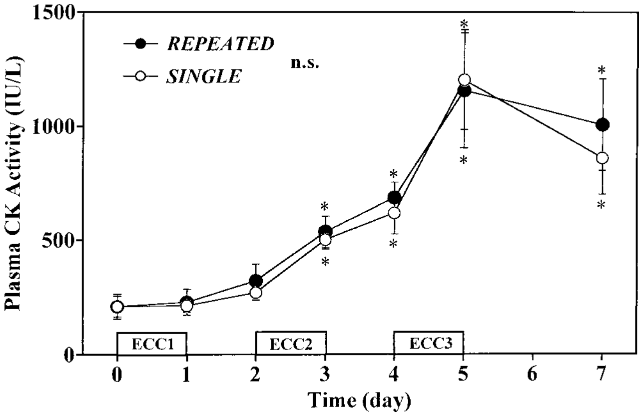

Figure 6. Changes in plasma CK activity after eccentric exercise in single-bout (SINGLE) and repeated-bout (REPEATED) conditions. * = significant ($p < 0.05$) difference from the pre-exercise level. n.s. = not significantly different.

third exercise session (Figure 4). The amount of increase in CIR from immediately after ECC1, ECC2, and ECC3 in the REPEATED condition was not significantly different (Figure 4).

Muscle Soreness

Although no muscle soreness developed immediately postexercise, it developed and peaked 1–2 days after exercise, subsided gradually, and disappeared by 5 days after exercise for both SINGLE and REPEATED conditions (Figure 5). Excluding the changes immediately after ECC2 and ECC3, no significant difference in soreness was evident between the SINGLE and REPEATED conditions (Figure 5). In the REPEATED condition, significant ($p < 0.05$) decreases in soreness were found immediately after the ECC2 (from 37 to 30 mm) and ECC3 (from 16 to 8 mm).

Plasma CK Activity

No significant increase in CK was evident 1–2 days postexercise, although by 3 days after exercise significant ($p < 0.01$) increases from pre-exercise levels were apparent (Figure 6). CK peaked 5 days after exercise (approximately 1,200 $IU \cdot L^{-1}$) for both conditions, and was still significantly ($p < 0.05$) elevated from the pre-exercise level at 7 days postexercise (Figure 6). No significant difference in changes was observed between the SINGLE and REPEATED conditions.

Discussion

A submaximal eccentric load representing 50% of the MIF at 90° (1.57 rad) of elbow flexion was used in this study. After maximal eccentric exercise of the elbow flexors, in which the elbow flexors are forcibly lengthened by applying a higher external force, plasma CK activity often exceeds 20,000 $IU \cdot L^{-1}$, the decrease in ROM is larger than 30°, increase in CIR is larger than 20 mm, and MIF is still less than 60% of the pre-exercise value at 5 days after exercise (14). However, the eccentric exercise of the present study resulted in a lower CK peak (≈1,200 $IU \cdot L^{-1}$, Figure 6), smaller changes in ROM (≈15°, Figure 3) and CIR (≈10 mm, Figure 4), and faster recovery of MIF (more than 80% at 5 days postexercise, Figure 2). These data suggest that the magnitude of muscle damage after the submaximal eccentric exercise protocol used in the present study was not as large as that after maximal eccentric exercise. The submaximal eccentric exercise protocol in the present study is more in line with that used in resistance training than is maximal eccentric exercise. Interestingly, the development of muscle soreness after the submaximal eccentric exercise was similar to that reported in other studies involving maximal eccentric exercise. This suggests that soreness does not seem to indicate the magnitude of muscle damage (3, 17).

The present study attempted to address the question of whether performing repeated bouts of eccentric exercise at an early recovery stage from an initial eccentric bout causes more muscle damage and retards recovery. After excluding the changes immediately postexercise for the REPEATED bouts, changes in MIF (Figure 2), ROM (Figure 3), SOR (Figure 5), and CK (Figure 6) were not significantly different between the SINGLE and REPEATED conditions. Although the change in CIR was significantly larger in the REPEATED condition at days 3 and 5, this difference was no longer evident at 7 days postexercise (Figure 4). Since the increases in CIR after ECC2 and ECC3 did not exceed that seen immediately after ECC1 and the difference between the conditions was small (Figure 4), it is unlikely that the difference between the condition indicates that repeated bouts exacerbated muscle damage and retarded the recovery process. These results were in line with previous studies (6, 14) that showed that performing repeated bouts of eccentric exercise 3 and 6 days after the first bout did not result in further damage or retard the recovery process. Smith et al. (20) reported that repeating a bout of eccentric exercise at 48 hours after the first bout did not influence the time course of DOMS, CK, and strength. The present study confirmed that no additional muscle damage was induced, and the recovery was not affected, when a repeated bout was performed 48 hours after the first bout. In addition, the results of this study showed that additional eccentric exercises performed 2 and 4 days after an initial eccentric bout did not exacerbate muscle damage and retard the recovery process.

In the REPEATED condition, MIF dropped to approximately 50% of the pre-ECC1 level immediately after each exercise bout, but the amount of decrease in MIF in ECC2 and ECC3 was significantly smaller than that in ECC1 (Figure 2). It seems reasonable to assume that if there are damaged muscle fibers, intact fibers compensate for the damaged fibers and are exposed to higher eccentric loading per fibers in the subsequent bouts. This would result in a further force loss. However, ECC2 (57 N) and ECC3 (68 N) did not produce the same amount of force loss as that seen after ECC1 (90 N). This phenomenon has also been reported in previous studies in which the repeated bouts were performed 2 and 4 weeks (12), or 3 and 6 days (6, 13) after the first bout. It might be that a population of muscle fibers is not affected or damaged by eccentric exercise (12) and can maintain the force generation ability. This could be the reason for no further changes in indicators of muscle damage (Figures 2–6) after ECC2 and ECC3. Paddon-Jones et al. (15) recently reported that when maximal isokinetic eccentric exercise was repeated 2 days after the initial bout, the recovery time course was not significantly altered, although MIF immediately after the second bout was significantly lower than that after the first bout. In the present study, even if ECC2 and ECC3 resulted in larger decreases in MIF, it seems unlikely that they exacerbate muscle damage and substantially affect the recovery. Further studies are necessary to confirm the results of Paddon-Jones et al. (15), and to investigate whether performing more demanding eccentric exercise in the subsequent bouts influences the recovery process.

It is interesting to note that muscle soreness decreased significantly immediately after ECC2 and ECC3 (Figure 5). Soreness seems to be exacerbated upon initiation of movement of sore muscles; however, it improves as exercise continues. Saxton and Donnelly (18) also reported that a temporary relief of muscle soreness was evoked by performing light concentric exercise 2 days after eccentric exercise. However, explanations for this phenomenon are not forthcoming, and warrant further study. It is also important to note that ECC2 and ECC3 did not appear to accelerate the recovery of muscle function (Figures 2 and 3). It has been documented that prolonged rest may delay recovery of musculoskeletal injury and that early resumption of activity can promote restoration of function (4, 9). It might be that early mobilization is beneficial for the recovery from eccentric exercise-induced muscle damage; however, repeating the same eccentric exercise does not seem to expedite the recovery process.

In summary, the present study confirmed previous studies (6, 7, 10, 13, 15, 20) that additional eccentric exercise performed in the early recovery phase does not exacerbate muscle damage or affect the recovery process, and suggests that muscles can tolerate submaximal eccentric loading every other day. Although no further muscle damage seems to be induced and recovery is not retarded by performing subsequent eccentric exercise bouts during recovery from an initial damaging exercise, whether this type of training is beneficial is unresolved. As muscles cannot produce as high a force as the initial bout after damaging exercise, including additional eccentric exercise sessions may result in no positive acute training effect; however, chronic effects of this type of training remain to be examined.

Practical Applications

Resistance training is often performed with sore muscles. It has been assumed that providing sore muscles additional damaging exercise during the early recovery period exacerbates muscle damage and retards the recovery process. The present study examined whether negative effects would be observed in untrained subjects, when 3 sets of 10 submaximal eccentric actions of the elbow flexors were performed 3 times per week on every other day. No significant differences in changes in indicators of muscle damage were observed between the repeated-bout condition and a single-bout condition. This suggests that when training sore muscles, no additional muscle damage is induced and recovery is not affected by the additional exercise bouts. However, it should be ascertained that the soreness is DOMS caused by eccentric biased exercise. It should also be borne in mind that strength is often lower than normal when DOMS develops. It seems difficult to generate maximal force in damaged muscles, and it may be risky to use these weakened muscles. It is also important to note that this study used untrained subjects. It may be possible that responses of trained individuals are different from an untrained population; however, it is unlikely that trained individuals have more muscle damage and slower recovery from performing eccentric training than untrained individuals.

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