Effects of Exhaustive Dumbbell Exercise After Isokinetic Eccentric Damage: Recovery of Static and Dynamic Muscle Performance

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Abstract

Sakamoto, A, Maruyama, T, Naito, H, and Sinclair, PJ. Effects of exhaustive dumbbell exercise after isokinetic eccentric damage: recovery of static and dynamic muscle performance. *J Strength Cond Res* 23(9): 2467–2476, 2009–This study examined the recovery of static and dynamic muscle performance after eccentric damage with and without repeated exercise, using different exercise modes between the initial and subsequent exercise bouts. Twelve nonweight-trained adults performed both control and repeated exercise conditions. Soreness, limb circumference, static joint angles, creatine kinase (CK), isometric strength, and dynamic muscle performance involving a stretch-shortening cycle (SSC) were monitored for 7 days to evaluate the recovery. After baseline measures, subjects performed 30 maximal isokinetic eccentric contractions (90 degrees/second) of the elbow flexors in each experiment. For the control condition, no treatment was applied. For the repeated exercise condition, 5 sets of arm curls using dumbbells (70% isometric maximal voluntary contraction of each testing day) were performed until failure on days 1, 2, 3, and 5 of recovery. Significant condition vs. time interactions existed in circumference ($p = 0.012$), static relaxed angle ($p = 0.013$), isometric strength ($p = 0.039$), and dynamic extension angle ($p = 0.039$), suggesting a slightly delayed onset of recovery with the repeated exercise. SSC performance changed more in parallel with soreness after eccentric exercise than did the other measures. It was concluded that the repeated bout effect was present, although slightly reduced, when subsequent exercise performed before recovery was intense and differed in mode from the initial eccentric exercise. Practical applications of this research are that resistance training may be continued after eccentric damage; however, a minor delay in the onset of recovery may occur depending on training modes. Muscle soreness is a good indicator of performance decrement during dynamic movements following eccentric damage.

Key Words DOMS, strength, stretch-shortening cycle, repeated bout effect

Introduction

High-intensity eccentric exercise has been shown to result in muscle damage, with symptoms including delayed-onset muscle soreness (DOMS), strength loss, restricted range of motion (ROM), and increased blood protein (9,27). The exercised muscles, however, initiate a protective adaptation so that repeating the same eccentric-biased exercise after recovery results in markedly reduced symptoms of damage compared to those resulting from the initial bout (10–12). This phenomenon has been well described as the repeated bout effect (22,25). The mechanisms of the repeated bout effect are not fully understood but have been explained by neural, mechanical, and/or cellular adaptations (3,22).

The repeated bout effect can also be observed before full recovery from eccentric damage so that further physical stress on the affected muscles in the early recovery phase, even only 24 hours after the initial eccentric exercise, does not exacerbate or delay the rate of recovery (4–6,26,28,36,39). It has therefore been implied that individuals may still continue training while suffering from DOMS without significant risk of further damage (6,25). This second form of the repeated bout effect, observed before recovery from the initial damage, is the major focus of this paper.

Although cellular adaptations have been proposed to explain the protection from injury recurrence that occurs after recovery from initial eccentric damage (22), these explanations may not be applied to the protective adaptation seen in early recovery because the short duration would not allow time for these adaptations to occur. One likely mechanism for the lack of further damage resulting from exercise during the recovery period is the loss of strength following eccentric

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damage. The force levels associated with repeated exercise bouts are therefore of a lower intensity and less likely to induce further injury (8,28).

A further explanation why additional exercise stress before full recovery does not exacerbate muscle damage may be that sarcomere disruption resulting from eccentric damage does not extend across a whole muscle fiber, with myofibrils adjacent to those damaged appearing relatively normal (9). In fact, morphological evidence by Friden et al. (14) demonstrated that in some of their samples, only 1 z-band from a single myofibril was disrupted. In an eccentrically damaged muscle, therefore, additional workload on subsequent days may be distributed to the intact myofibrils and would not affect recovery of the damaged myofibrils.

The repeated bout effect has been extensively observed under conditions where the same or similar types of eccentric-biased exercise were used for both the initial damage-inducing exercise and for the repeated bouts (4,6,12,25,26,28). In practical situations, even well-trained muscles can experience DOMS after performing unfamiliar movements. Therefore, the magnitude of protective adaptation against subsequent eccentric exercise may decrease if the exercise involves a different motor unit recruitment pattern from the initial exercise. Moreover, it is unlikely that an exercise program would consist of just a single mode of exercise, with trainees usually undergoing several types of exercise stress during their training. Hence the previous finding, that subsequent exercise bouts before recovery from eccentric damage would not cause a significant exacerbation, should be confirmed using various modes of exercise to increase its applicability to any conceivable training situations. Chen (3) reported that integrated electromyography (iEMG) was lower during subsequent maximal eccentric exercise than for the initial bout, implying the contribution of a neural adaptation to protect the affected muscle. This reduction in iEMG was not, however, observed during isometric maximal voluntary contractions (MVC). This finding therefore suggests that the repeated bout effect may not be as pronounced for different modes of muscle contraction.

If the repeated bout effect occurs only when the repeated exercise mode is the same as that which originally causes muscle damage, then recovery after that initial exercise would be delayed by further unfamiliar exercise. Although concentric and dumbbell exercises have been used to investigate the subsequent stress after eccentric damage, these studies have been limited to either purely concentric exercise or, if eccentric loading has occurred, it has been at a very low intensity (30,32,36,39). It is therefore not surprising that the repeated exercise in these experiments has not delayed recovery from the original eccentric stress. To date, there have been no studies investigating whether the recovery from eccentric muscle damage is affected when using both a different mode of exercise and exercise of high intensity undertaken over multiple days to maintain the potential risks of further damage.

To assess the rate of recovery of muscle function, previous studies have been mostly concerned with isometric or isokinetic MVC and relaxed and flexed joint angles when not performing exercise (3,4,6,11,12,26,28,32). Contractions utilizing the stretch-shortening cycle (SSC), however, are the primary mode in most human activities when movements are fast and repeated continually. Therefore, the conventional measures described previously may not directly evaluate the recovery of dynamic performance. Although several studies have documented a decline in SSC performance after eccentric exercise or examined the recovery of SSC performance with and without therapeutic massage (1,13,34), no studies have used this approach to evaluate the recovery with and without repeated exercise.

The purpose of this study was to examine the recovery rate of muscles after an initial bout of eccentric exercise, in the presence of repeated bouts of high-intensity exercise, using a mode of contraction different to that of the initial eccentric loading. Recovery was assessed by conventional techniques (soreness, limb circumference, creatine kinase [CK] activity, static relaxed and flexed joint angles, and isometric MVC) and through measures of dynamic performance utilizing the stretch-shortening cycle (joint angular displacement, velocity, and acceleration). It was hypothesized that the magnitude of the repeated bout effect would be reduced when using a different mode of exercise so that recovery from the original eccentric damage would be delayed.

Methods

Experimental Approach to the Problem

This study was designed to investigate the recovery of elbow flexor muscles from eccentric muscle damage with and without performing a different mode of exhaustive resistance exercise for 4 days in the early recovery phase. The recovery rate was monitored using conventional measures including soreness, limb circumference for swelling, CK activity, static joint angles, and isometric MVC. Angular displacement, velocity, and acceleration of the elbow joint during the stretch-shortening cycle were also monitored as more practical measures of muscle performance. Subjects participated in a cross-over design with 1 arm performing repeated exercise and the other acting as a control. The 2 experiments were separated by more than a month to minimize the effect of the prior condition on subsequent measures, the order of assigned condition was randomized, and the number of dominant arms in each condition was counterbalanced. On the first experimental day, baseline values of the target variables were recorded, after which damage-inducing eccentric exercise was performed at maximal effort on an isokinetic dynamometer. Measurements were repeated immediately after the eccentric exercise and again on days 1, 2, 3, 5, and 7 of recovery. For the control condition, no specific treatment was given after the initial eccentric exercise. For the experimental condition, subjects performed subsequent exercise on days 1, 2, 3, and 5 after the criteria measurements.

To alter the mode of exercise after the initial damage, dumbbell arm curls utilizing both concentric and eccentric contractions were performed. This particular type of subsequent exercise was selected to make the exercise stress more practical and applied to resistance training situations, rather than utilizing more artificial isokinetic contractions. To maintain the potential risk for further damage, exercise loading was equivalent to 70% of isometric MVC recorded on each day of testing and lifting continued until failure to complete a contraction unaided, followed immediately by a further 3 spotted repetitions. Five sets were performed on each day of exercise.

Subjects

Twelve active healthy adults (7 men and 5 women; mean ± *SD* height 169.4 ± 8.1 cm; mass 69.0 ± 16.3 kg; age 25.9 ± 3.7 years), with no existing neuromuscular diseases or musculoskeletal injuries, voluntarily participated in the study. Although there have been suggestions that higher circulating estrogen levels may protect women against exercise-induced muscle damage, most recent studies have found little difference between genders in their recovery from eccentric exercise (7,31). Therefore, similar to the study of Chen and Nosaka (6), both men and women have been recruited for this study. All subjects, except 2 of the women, had previously experienced resistance training on a casual basis. None, however, had trained within the last 6 months or were familiar with maximal effort eccentric exercise or exhaustive dumbbell exercise.

To minimize the learning effect during the experiment, all subjects came to the laboratory on 2 occasions prior to each testing session and underwent the actual experimental procedure to become acquainted with the methodology and equipment. Verbal instructions were given for each of the exercise protocols. During the 7-day recovery period, subjects were allowed to perform normal daily activities but refrained from any physical exercise or training. Before participating in this study, all subjects read the guidelines for the procedure and gave informed consent. This study was approved by the ethics committee of the Tokyo Institute of Technology.

Procedures

Eccentric Exercise. Subjects were strapped to an isokinetic dynamometer (Biodex System 3, Biodex Medical System Inc., Shirley, New York, U.S.A.) and placed the tested arm on the armrest with 40 degrees of flexion and 30 degrees of abduction of the shoulder. The seat and lever positions were kept constant throughout the experiment for each subject. The range of lever movement was set between 10 degrees of flexion from the maximal extension angle and full flexion of the elbow joint. Eccentric stress was applied to the elbow flexors with the subjects maximally resisting the lever arm moving away from the flexed position at 90 degrees per second. The lever arm automatically returned to the flexed position at 60 degrees per second, during which subjects relaxed the tested arm without exerting force. The eccentric exercise bout consisted of 6 repetitions repeated for 5 sets, with a 1-minute rest included between sets.

Repeated Exercise. Seated upright arm curl exercise using both concentric and eccentric actions was performed for the repeated exercise condition on days 1, 2, 3, and 5 of recovery. The exercise was performed on a preacher curl bench (Bodymaker, BB-Sports Co., Ltd, Osaka, Japan) with the subject sitting backward on the bench and the back resting against the arm pad so that back-sway motion could be minimized. The posterior surface of the exercising arm was also lightly touching the pad to control for unwanted shoulder flexion; thus, exercise stress was concentrated on the elbow flexors. Previous studies have provided evidence that motor unit recruitment differed between isokinetic and isotonic contractions and between eccentric and concentric contractions (16,20,29,33). Therefore, it was assumed that this type of exercise would elicit a different pattern of motor unit recruitment from that used in the initial eccentric exercise while the same muscle group was used.

The exercise intensity was equivalent to 70% of isometric MVC value obtained on each testing day, which was converted to mass in kilograms for weight selection. Pilot testing indicated that this intensity allowed a high level of effort, whereas exceeding this intensity often resulted in failure to perform the first concentric repetition for some individuals. Arm curls were continued until lifting failure using the full range of motion, and then the investigator immediately spotted the subject's hand to provide 3 extra repetitions to ensure a significant stress on the muscle. Lifting speed was not specifically controlled, but the subjects were instructed to spend more than 2 seconds during the eccentric phase. The lifting speed was maintained as consistently as possible during the spotted repetitions within each set. Five sets of the exercise were performed on each day, with a 5-minute rest between sets.

Experimental Landmarks. Using a semi-permanent marker, the humeral line (between the greater tubercle and the head of radius) and radial line (between the head and the styloid process of the radius) were drawn. Next, 3 transversals to the humeral line were drawn across the median point (line A) and 3 cm above (line B) and below (line C) the line A. Subjects were instructed not to completely rub out these landmarks throughout the experiment to ensure the consistent measurement sites.

DOMS. Soreness was evaluated using a customized 10-cm visual analogue scale with the left end, middle point, and the right end, respectively, representing no soreness, most severe muscle soreness ever experienced, and extreme soreness. Subjects rated the soreness on an attempt to maximally extend (SORext) and flex (SORflex) the elbow joint, and the distance between the left end and the marked point represented the level of perceived soreness (to 1 decimal place). An additional 5-cm line extended from the right end of the scale in a pale color. This additional scale was used only if subjects rated soreness as extreme on 1 day but then experienced even greater soreness on later days.

Circumference. The circumferences over the lines A, B, and C were measured with a tape measure. During measurement, the elbow joint was flexed at 90 degrees while subjects were seated on the dynamometer without contracting the muscle, so that the measurements were taken under a constant joint angle throughout the experiment. The average value from the 3 measured sites was used for data analysis.

Creatine Kinase Activity. Approximately 32 μL of the blood was drawn from a fingertip of the contralateral arm. The blood was examined by Reflotron Plus dry chemistry strips analyzer (Reflotron Plus, Roche Diagnostics Division, Basel, Switzerland) for CK activity, which indirectly estimated the mechanical disruption of the affected muscle tissues (19). If CK activity exceeded the capacity of the device (approximately 1,500 UI), the blood was diluted by normal saline solution to render it within the measurable range and then corrected to the undiluted value.

Static Joint Angles. The relaxed and flexed angles of the elbow (RANG and FANG) were measured using an electrogoniometer (Biometrics SG110, Biometrics Ltd., Ladysmith, Virginia, USA), attached on the humeral and radial lines described earlier. Subjects stood in the anatomical position during the measurement of RANG. For the FANG, subjects attempted to actively flex the elbow joint as far as possible.

Isometric Strength. Using the dynamometer, isometric contractions were performed for 3 seconds while the elbow was flexed at 90 degrees. Average torque over the last 1 second was recorded as the isometric torque value. The mean from 2 trials was used for statistical analysis.

SSC Performance. SSC performance was evaluated using an original method. Subjects sat on the preacher curl bench facing forward to the arm pad, with a light dumbbell (0.5 kg) gripped in the hand of the tested arm and the goniometer attached on the humeral and radial lines. Starting with the elbow maximally flexed, they relaxed the elbow flexors and lowered the forearm until maximal achievable elbow extension (dynamic extension angle) but making no significant physical contact with the pad of the bench. The instant the forearm reached the lowest position, an explosive concentric contraction followed at maximal effort until full elbow flexion (dynamic flexion angle) by utilizing the enhancing effects of the stretch-shortening cycle. The goniometer recorded the joint angle over time and, using the obtained data, joint angles (dynamic extension and flexion angles), peak angular acceleration, and peak velocity of the elbow movement were calculated during both the lowering and concentric phases. Mean values from 2 trials were used for statistical analysis. Pilot work showed that concentric performance was significantly improved after making the lowering motion when compared with concentric-only motion (peak velocity: 972.0 ± 221.7 vs. 873.6 ± 145.1 degrees/second, $p = 0.003$; peak acceleration: 7651.4 ± 1593.5 vs. 6238.7 ± 1456.0 degrees/second^2, $p < 0.001$).

Goniometer data (static joint angles and SSC performance) were processed by Powerlab Chart 5 software (ADInstruments, Castle Hill, Australia). The output signals were collected at 400 Hz, calibrated, and then low-pass filtered (5 Hz, Butterworth filter) prior to data processing.

Statistical Analyses

Statistical tests were conducted using SPSS (15.0) software. Test-retest reliability was evaluated using the data obtained on the second familiarization day and the baseline values were evaluated by intraclass correlation coefficient (ICC) (37). The ICCs of circumference, CK, static joint angles, and isometric strength were reasonably high, ranging from 0.81 to 0.99. The SSC variables were more variable, with ICCs ranging between 0.63 and 0.86 ($\bar{X} = 0.75$). Peak lowering velocity demonstrated the lowest level of repeatability and was the only variable to display an ICC less than 0.7 (ICC = 0.63).

The main effects of condition (repeated exercise or control) and time (baseline, immediately after, day 1, day 2, day 3, day 5, or day 7) were assessed using 2-way repeated-measures analysis of variance (ANOVA). If a significant time effect was detected, pairwise comparisons were performed using Bonferroni adjustment (38). When the assumption of equal variances was violated, significance was adjusted using the Huynh-Feldt method. The baseline values and the total work done during the eccentric exercise between the 2 conditions were compared using paired *t*-tests. The level of 0.05 was adopted for statistical significance and all presented values are expressed as mean ± *SD*.

Results

The baseline values did not significantly differ between the control and repeated exercise conditions on any variable. Similarly, the total work done during the eccentric exercise over 5 sets also did not differ between the conditions (control 2,083.2 ± 850.1 J; repeated exercise 2,136.0 ± 793.3 J). The number of repetitions performed before spotting and the mass of weights lifted during the repeated exercise are shown in Table 1. The average exercise load ranged from 4.1 to 5.5 kg, corresponding to 13 to 21 repetitions maximum (RM) (Table 1, Set 1).

DOMS

The elbow flexor muscles experienced significant soreness after eccentric exercise from day 1 on both extension ($p < 0.001$) and flexion ($p < 0.001$) of the elbow joint, with maximal soreness being observed on day 3 (Figure 1). The degree of soreness did not differ significantly between conditions for either extension or flexion of the elbow joint, with no interaction by time.

Table 1. Number of repetitions performed and the mass of weights lifted during repeated exercise.

Day	Repetitions					Mass (kg)
	Set 1	Set 2	Set 3	Set 4	Set 5	
1	13 ± 4	10 ± 4	8 ± 4	6 ± 4	6 ± 3	4.3 ± 1.5
2	21 ± 12	13 ± 5	11 ± 3	10 ± 4	7 ± 4	4.1 ± 1.4
3	19 ± 12	14 ± 6	12 ± 5	11 ± 5	10 ± 6	4.3 ± 1.6
5	14 ± 7	11 ± 5	9 ± 5	9 ± 4	8 ± 4	5.5 ± 2.3

Values are mean ± *SD* for 12 subjects. The number of repetitions is shown excluding the 3 spotted repetitions. The mass of weights lifted during repeated exercise were calculated from 70% of isometric MVC on each day of testing.

Circumference

Circumference gradually increased over the recovery period ($p < 0.001$) with no differences between conditions (Figure 2). A significant interaction between condition and time ($p = 0.012$) indicated, however, that circumference continued to increase throughout the study period with repeated exercise, whereas it started to recover after day 5 for the control.

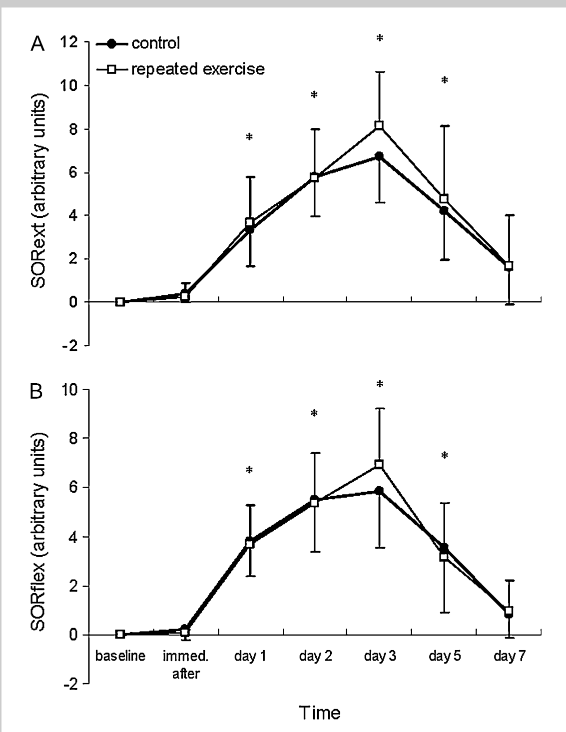

Figure 1. Subjective rating of soreness on elbow extension (A) and flexion (B) for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$, values significantly different from the baseline.

Static Joint Angles

RANG increased immediately after eccentric exercise for both conditions ($p < 0.001$, Figure 3A). RANG produced a significant condition effect ($p = 0.047$), with the angle being slightly greater with repeated exercise. Post hoc analysis suggested, however, that this condition effect could be attributable to an offset in baseline values between the control and repeated exercise conditions. Although a paired *t*-test found no significant difference between baseline values for RANG, the main effect for condition was eliminated when the ANOVA was re-run using normalized values, calculated as absolute changes from the baseline. The interaction between condition and time effects was, however, significant when ANOVA was performed with either raw or normalized values ($p = 0.013$).

FANG demonstrated no condition differences or interaction by time (Figure 3B). A significant reduction in FANG was seen immediately after eccentric exercise, and this reduction remained by similar amount until day 3, followed by a gradual recovery thereafter ($p < 0.001$, Figure 3B).

Creatine Kinase

CK activity increased significantly following eccentric exercise ($p = 0.005$) with no significant condition effect or interaction by time (Figure 4). Because of the large variance, pairwise comparisons found no specific days to be significantly different than the baseline.

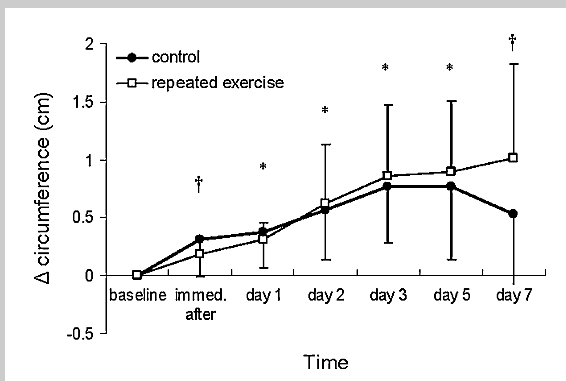

Figure 2. Absolute change in limb circumference from baseline for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

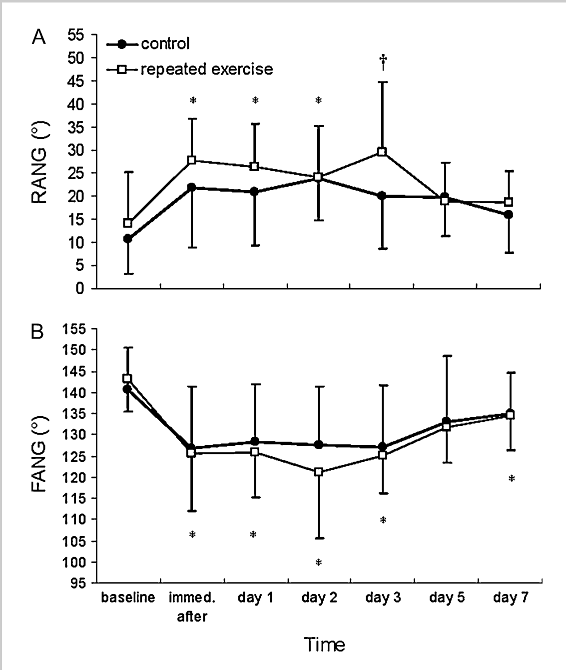

Figure 3. Relaxed (A) and flexed (B) elbow joint angles for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

Isometric Strength

Isometric strength significantly decreased after eccentric exercise (Figure 5, $p < 0.001$). Although there was no significant condition effect, a significant interaction between condition and time existed ($p = 0.039$). For the control condition, maximum impairment in strength was observed immediately after eccentric exercise followed by a gradual recovery thereafter. With repeated exercise, however, the decline in strength remained relatively constant between days 0 and 3, followed by a gradual improvement.

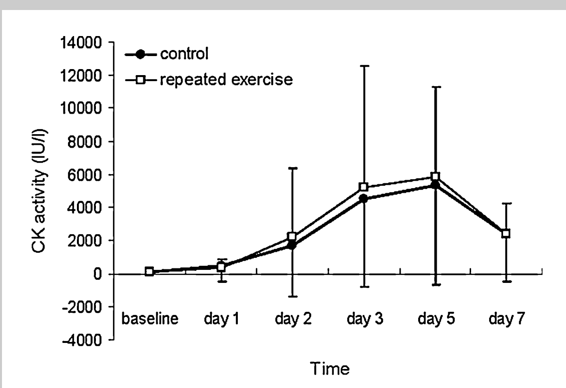

Figure 4. CK activity for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation.

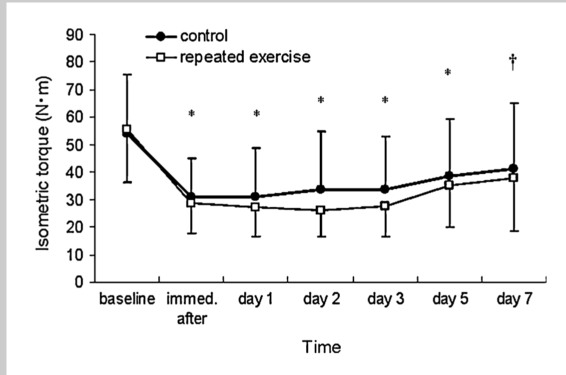

Figure 5. Isometric torque for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

SSC Performance

Dynamic extension angle during the SSC task increased after eccentric exercise ($p < 0.001$), with maximum impairment seen on day 2 or 3. There was no significant main effect for

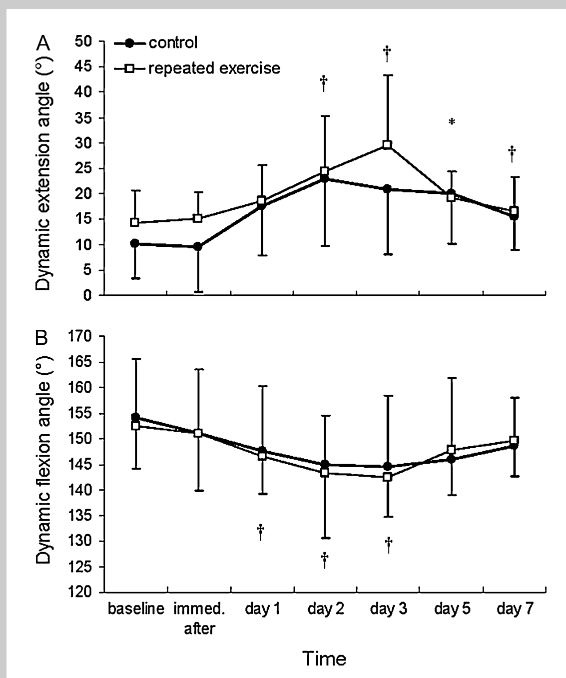

Figure 6. Dynamic extension (A) and flexion (B) angles during the stretch-shortening cycle (SSC) movement for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

condition; however, the interaction between condition and time was significant ($p = 0.039$, Figure 6A) with the onset of recovery appearing to be delayed for the repeated exercise condition.

A significant reduction in dynamic flexion angle was seen from day 1 ($p = 0.002$), with no main effect for condition or condition–time interaction (Figure 6B). The maximum reduction in the flexion angle was seen on day 3, followed by a gradual recovery thereafter.

Peak lowering velocity of the elbow joint decreased after eccentric exercise, with the maximum reduction being observed on day 2 or 3 ($p < 0.001$, Figure 7B). There was no significant change in peak lowering acceleration over time ($p = 0.059$, Figure 7A). Nor was there a significant condition effect or condition vs. time interaction for either velocity or acceleration during lowering.

Peak concentric acceleration and velocity of the elbow joint continuously decreased until day 2 or 3 and then returned toward baseline thereafter ($p < 0.001$, Figure 8). No significant condition effect or condition vs. time interaction was found for either variable.

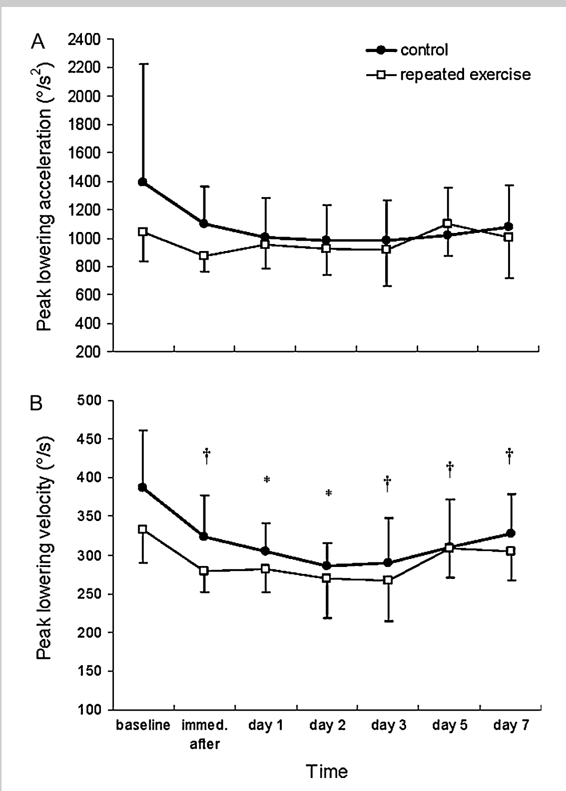

Figure 7. Peak angular acceleration (A) and velocity (B) during the lowering phase of the stretch-shortening cycle (SSC) movement for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

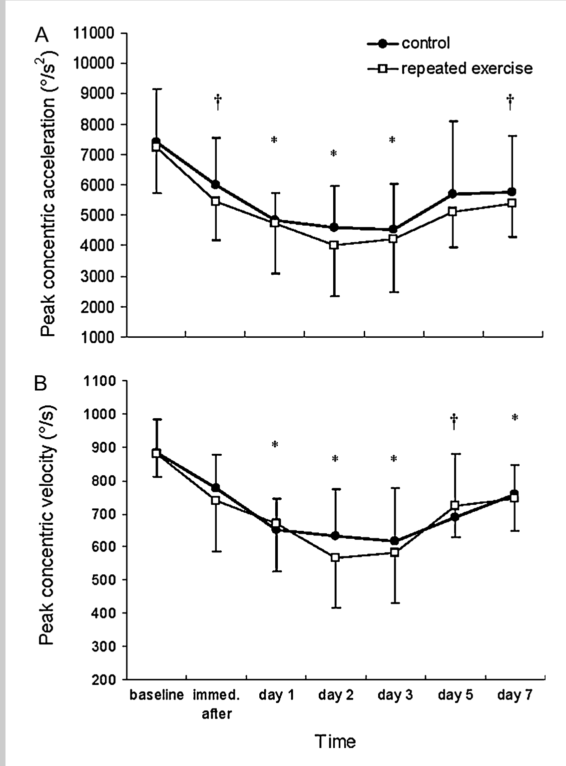

Figure 8. Peak angular acceleration (A) and velocity (B) during the concentric phase of the stretch-shortening cycle (SSC) movement for control and repeated exercise conditions ($n = 12$). Data represent mean values ± standard deviation. *$p < 0.01$; †$p < 0.05$, values significantly different from the baseline.

Discussion

This study investigated the recovery patterns of reduced muscle performance after maximal isokinetic eccentric exercise, with and without subsequent exhaustive dumbbell exercise undertaken during the recovery phase. Dumbbell exercise was chosen to investigate whether using a different mode of exercise during recovery would affect the repeated bout effect, which has been well studied under conditions where the same exercise mode was used for both the initial and repeated exercise bouts. Prior research has shown differences in recruitment patterns between isokinetic and isotonic contractions (29,33), between eccentric and concentric exercise (16,20), and between rested and fatigued muscles (24). Therefore, we postulated a priori that selective recruitment of specific adaptable or intact fibers may be compromised in the subsequent exercise bouts, reducing the effectiveness of the repeated bout effect.

A significant condition vs. time interaction existed in circumference ($p = 0.012$), RANG ($p = 0.013$), isometric strength ($p = 0.039$), and dynamic extension angle ($p = 0.039$, Figure 2, 3A, 5, and 6A). These data suggest that the onset of recovery has been delayed by the repeated dumbbell exercise. It is possible that the delay in recovery was a result of accumulated muscle fatigue from the repeated exercise, especially during the first 3 consecutive days of exercise. Chen and Hsieh (4), however, demonstrated no alteration in the recovery, even when their subjects performed repeated maximal eccentric exercise for 7 consecutive days. This suggests, therefore, that a reduction in the repeated bout effect is the likely explanation for the delayed onset of recovery; resulting from either aggravation of the original damage, or through small amounts of additional damage in motor units that were not highly active during the initial eccentric exercise.

Nonetheless, the observed effect of repeated exercise in the present study was only to delay the onset of recovery in some of the measures, and the recovery rate thereafter appeared to be similar with no clear signs of exacerbation. Circumference was the only measure that failed to return toward baseline with repeated exercise within the study period (Figure 2). The delayed onset of recovery with the repeated exercise in this study can therefore be considered to be only minor. Consequently, the main finding of this study is that the repeated bout effect in the early recovery phase still exists for an altered mode of exercise, supporting the previous implication that enthusiastic trainees may continue physical activities while suffering from DOMS.

Given the minor changes observed during recovery using different exercise modes, a question still remains whether this implication would hold if other types of exercise were used for the initial and subsequent bouts. Various combinations of exercise types should be tested using power, ballistic, plyometric, or other resistance training to better ascertain the implication of our study for a wide range of training situations.

The decline in performance after eccentric damage was severe in this study, with average isometric strength decreasing to 55% of baseline immediately after eccentric exercise. Although subsequent dumbbell exercise required a considerable effort, the absolute loading eventually became low (4.1–5.5 kg on average) when compared to the original maximum strength. If less damage had been produced in the initial eccentric exercise and the reduction in isometric MVC was smaller, higher loading exercise could have been performed in subsequent exercise bouts. This may have increased the likelihood of exacerbating the original damage. Future research may need to test the current research hypothesis using less severe muscle damage.

A further limitation of the present results is that the majority of measured criteria did not return to the baseline within the experimental period (up to 7 days), although prior literature suggested this duration would be sufficient (1,8,9,13,35). Further effects of condition may therefore have appeared in subsequent days. Sayers et al. (32) have reported that the treatment difference became significant in torque recovery as of day 9 when comparing 3 treatments (immobilization vs. control vs. light exercise), with the control condition producing the slowest recovery. Consequently, it is recommended that future research into recovery after eccentric damage should investigate a period longer than 7 days.

A secondary finding of the current study is that the time course of changes after initial eccentric exercise differed between static and SSC conditions. Most conventional variables (circumference, static joint angles, and isometric MVC) did not change in parallel with soreness with the correlation between static measures (circumference, static joint angles, CK, and isometric torque) and muscle soreness (SORflex) being only 0.34 (Figures 1–5). This is not surprising because it has been well established that the change in these variables after eccentric exercise is related more to peripheral perturbation rather than to perceived pain (10,17,18,21,23). Unlike many other studies on eccentric damage, our MVC values were averaged from a relatively longer contraction time (the last second was recorded from a 3-second contraction), rather than collecting the instant peak value. This method may give more chance for pain to provide central feedback on torque production. The current results were, however, still in agreement with previous MVC data, demonstrating independent time-course changes between the severity of DOMS and isometric strength (Figures 1 and 5). This further supported the contention that pain does not explain the loss of MVC ability.

By contrast, dynamic muscle functions involving SSC (dynamic joint angles, concentric and lowering accelerations, and velocities) decreased more in parallel with muscle soreness (r = 0.87, Figures 1, 6–8), which suggests a contribution of central inhibition via pain to the performance loss. This particular time-course behavior of performance change after eccentric exercise is consistent with previous studies of vertical jump and peak cycling power (1,13), suggesting that complex dynamic movements are more affected by pain because the damaged muscles are quickly stretched and shortened during the movement, causing powerful pain stimuli. Moreover, the exaggerated pain may, in turn, result in fear of sudden movements (15). It is not surprising that all subjects in this study claimed that the pain was extreme during the SSC task, although they all managed to perform the movements. In the SSC condition, therefore, it seems likely that both peripheral perturbation and central inhibition may account for the performance loss after eccentric exercise. Although this deduction is not conclusive, the current data together with the previous observations (1,13,15) provide a reasonable rationale for further studies to confirm this relationship between SSC performance and central command with DOMS.

In addition to the context of peripheral or central disturbances, a further explanation for the decreased dynamic performance after eccentric exercise, especially the concentric peak velocity, may be a failure to effectively utilize the enhancing properties of the SSC. Research has shown that faster stretching rates, together with longer muscle lengths and shorter time elapsed at the phase transition, play important roles to augment the SSC effect (2). In the present study, the impaired lowering joint angle and velocity, and the reduced peak concentric acceleration, indicated that these specific abilities to utilize the benefit of SSC were all reduced after eccentric exercise.

Our results, therefore, suggest the possibility that eccentric damage impairs dynamic performance by affecting the muscle itself, the level of motor command via exaggerated pain, and the enhancing effects of the stretch-shortening cycle. However, further investigations are required to fully justify this hypothesis.

In conclusion, the repeated bout effect was present, but slightly reduced, when subsequent exercise performed in the early recovery phase was intense and differed in mode from the initial damage-inducing eccentric exercise. In addition, dynamic muscle performance involving the stretch-shortening cycle changed more in parallel with soreness than did static measures during the recovery from eccentric exercise.

Practical Applications

Enthusiastic trainees may continue resistance training while suffering from delayed-onset muscle soreness without causing a major exacerbation of the existing damage. People should be aware, however, that a minor delay in the onset of recovery may occur if the subsequent exercise is intense and requires a different pattern of motor unit recruitment from that which caused the original damage.

Further training after eccentric damage may only be recommended, however, if the primary reason is to avoid prolonged detraining. Skill practice or competition may not be suitable to perform after eccentric injury because the muscle performances are significantly impaired.

Dynamic joint angles, acceleration, and velocity during rapid stretch-shortening cycle movement decreased more in parallel with the severity of soreness than did static measures of muscle performance. Muscle soreness, therefore, may be a good indicator of performance decrement during dynamic movements that follow eccentric damage.

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