EFFECTS OF A STRENGTH TRAINING SESSION AFTER AN EXERCISE INDUCING MUSCLE DAMAGE ON RECOVERY KINETICS

ABD-ELBASSET ABAÏDIA,¹,³ BARTHÉLÉMY DELECROIX,¹,³ CÉDRIC LEDUC,² JULIEN LAMBLIN,³ ALAN MCCALL,⁴ GEORGES BAQUET,¹ AND GRÉGORY DUPONT¹,³,⁴

¹Multidisciplinary Research Unit Sport Health Society, EA 7369 - URePSSS, University of Lille, F-59000 Lille, France; ²University of Picardie Jules Verne, Amiens, France; ³Lille Football Club, Camphin-en-Pévèle, France; and ⁴Edinburgh Napier University, Edinburgh, Scotland

ABSTRACT

Abäidia, A-E, Delecroix, B, Leduc, C, Lamblin, J, McCall, A, Baquet, G, and Dupont, G. Effects of a strength training session after an exercise inducing muscle damage on recovery kinetics. J Strength Cond Res 31(1): 115–125, 2017—The purpose of this study was to investigate the effects of an upper-limb strength training session the day after an exercise inducing muscle damage on recovery of performance. In a randomized crossover design, subjects performed the day after the exercise, on 2 separate occasions (passive vs. active recovery conditions) a single-leg exercise (dominant in one condition and nondominant in the other condition) consisting of 5 sets of 15 eccentric contractions of the knee flexors. Active recovery consisted of performing an upper-body strength training session the day after the exercise. Creatine kinase, hamstring strength, and muscle soreness were assessed immediately and 20, 24, and 48 hours after exercise-induced muscle damage. The upper-body strength session, after muscle-damaging exercise accelerated the recovery of slow concentric force (effect size = 0.65; 90% confidence interval = −0.06 to 1.32), but did not affect the recovery kinetics for the other outcomes. The addition of an upper-body strength training session the day after muscle-damaging activity does not negatively affect the recovery kinetics. Upper-body strength training may be programmed the day after a competition.

KEY WORDS active recovery, hormones, muscle regeneration

INTRODUCTION

Whether competing or training, athletes perform many eccentric actions that lead to muscle damage (23). As a result, muscle function and performance are reduced (40), and a period of recovery is required to return to the initial level of performance. Elite athletes are frequently required to play several competitions during the same week. However, as actions leading to muscle damage delay recovery of performance, the time between 2 competitions may be too short to fully recover (26). Some specific recovery strategies such as cold-water immersion, massage, nutrition, and sleep are effective to accelerate performance recovery and/or to decrease muscle soreness (25). Some of these recovery strategies need to be implemented immediately after the exercise-inducing muscle damage to have the maximum benefit (25). However, implementation of such strategies immediately after an exercise can delay the players’ time “to go to bed” and consequently diminishing sleep duration. As a consequence, implementation of some strategies immediately after a competition may negatively affect the ability to sleep/duration of sleep (24). It would therefore be interesting to identify which recovery strategies could be beneficial to implement the day after a competition. An important consideration could be to identify which recovery strategies are the most suitable to stimulate muscle regeneration process.

Cycling and/or running at a low intensity is widely used in sports to accelerate lactate removal after an exercise (25). However, results of studies that focused on using active cycling and/or running the day after an exercise showed neither positive nor negative effects of active recovery on performance (1).

Strength training may also represent an alternative technique of active recovery to accelerate muscle performance recovery. When muscle damage occurs, a regeneration process starts, with the goal of repairing the injured myofibrils (8). This process is mediated by satellite cell activation and proliferation (14). Several hormones such as insulin-like growth factor-1 (IGF-1), growth hormone, and testosterone are known to stimulate satellite cell activation and proliferation and protein synthesis (7,31,33). Additionally, it has been shown that performing strength training induces an increase of IGF-1 (21), growth hormone (21,32), and testosterone (21). As these hormones are implicated in the
regeneration process, one could hypothesize that implementing a strength session on the noninvolved limbs of the muscles previously damaged may improve performance recovery kinetics.

Although some studies have investigated the effects of a strength training session or a strength training program on hormone concentrations, to our knowledge no study has analyzed the effects of a strength training session after an exercise on the recovery of performance. The purpose of this study was to investigate the effects of a strength training session after an exercise-inducing muscle damage on performance recovery kinetics. It was hypothesized that a strength training session will accelerate the time to fully recover.

**METHODS**

**Experimental Approach to the Problem**

In a randomized crossover design, subjects performed an exercise inducing muscle damage: 5 sets of 15 eccentric knee flexors contractions on 1 leg. The next day, subjects performed either an upper-body strength training session (active recovery) or a passive recovery session. The active recovery session included 5 upper-limb resistance exercises, which have been shown to be effective at increasing testosterone and growth hormone concentrations (20,32). During the passive recovery session, subjects were seated in a room with a temperature of 18°C for 15 minutes. Subjects were assessed with a battery of tests before the muscle-damaging exercise (baseline values) and then immediately and 20, 24, and 48 hours after the muscle-damaging exercise protocol. Strength tests were performed after the recovery (20 hours) and 24 hours after the exercise to check if there was an immediate or a delayed effect of the strength training session on recovery kinetics. The battery of tests included hamstring concentric force (60 and 120°·s⁻¹), eccentric force (120°·s⁻¹), isometric force (60°) performed on an isokinetic dynamometer (Con-Trex MJ; CMV AG, Diübendorf, Switzerland) power during a single-leg countermovement jump (CMJ-IL) performed on a force plate (Kistler Instruments, Hampshire, UK), power during a single-leg speed test on a nonmotorized treadmill (Woodway Force 3.0; Woodway, Waukesha, WI, USA), creatine kinase (Reflotron; Roche Diagnostics, Grenzacherstrasse, Switzerland), thigh circumference, and muscle soreness. The experimental design is illustrated in Figure 1.

**Subjects**

Twelve physically active men (age 29.2 ± 5.5 years, 177.7 ± 7 cm, 76 ± 5 kg) participated in this study. Subjects were regularly involved in aerobic physical activity such as team sport, racket sport, or running. They were familiarized with strength training but they have never performed the sessions implemented in this study. They have been involved in this level of sports participation and strength training between 2 and 5 years. Subjects were all accustomed to performing at least 3 hours of physical activity per week and were without hamstring injury during the last 6 months. Subjects were instructed not to perform any muscular activity involving hamstrings or any strength training for any body part during the experimental period. Additionally, they were instructed not to eat protein before or after the recovery sessions or use other recovery strategies (specific guidelines of what constituted recovery strategies were provided). Nutritional guidelines were provided to each subject. Each subject was instructed to eat around 6–8 g·kg⁻¹ per day of carbohydrates and was allowed to drink water ad libitum. Each subject had to answer a questionnaire before each session to verify that the criteria were respected. All subjects provided written informed consent to participate to this study. This investigation was led in accordance with the guidelines provided by the local Ethics Committee in Biomedical Research.

**Procedures**

**Subjects’ Allocation.** Subjects were grouped in a randomized and balanced order to both conditions: control and experimental. Each condition was interspersed by 2 weeks. Dominant and nondominant legs were exposed to each condition in a randomized and balanced order. The order of recovery session was also randomized, and 4 combinations were allocated: nondominant leg + passive recovery, dominant leg + active recovery, nondominant leg + active recovery, dominant leg +
passive recovery. For strength tests and power tests, reliability was verified.

**Familiarization.** Subjects were familiarized with the battery of tests before the experimentations and baseline values were assessed before the experimental and control session. Before performing the tests for reliability, subjects were familiarized with the exercises (concentric force at 60 and 120°·s⁻¹, eccentric force at 120°·s⁻¹, isometric force at 60°, CMJ-1L and 1-leg power on nonmotorized treadmill) during 2 sessions with the isokinetic dynamometer, the force platform, and the nonmotorized treadmill. Then, 2 sessions were performed to determine the level of reliability. Before starting the second week of the experimentation (second leg), baseline strength values were tested again to avoid cross-adaptation consequences on force values (35). During each session, the investigator verbally encouraged subjects.

**Warm-Up.** Before the tests and the muscle-damaging exercise, a warm-up was performed consisting of 3 sets of 10 repetitions on a leg (hamstring) curl exercise. The intensity was progressively increased according to the Borg’s rate of perceived exertion (3). Subjects performed the warm-up at a perceived intensity of 11 (light), 13 (somewhat hard), and 15 (hard) during the first, second, and third sets, respectively.

**Exercise-Induced Muscle Damage.** Subjects performed hamstring exercise using the tested leg on an isokinetic dynamometer (Con-Trex MJ; CMV AG). The exercise was made up of 5 sets of 15 eccentric contractions at a speed of 60°·s⁻¹ interspersed by a 3-minute recovery. Approximately 30 minutes after the exercise, subjects were instructed to note the global intensity using the modified rate of perception scale from 0 (rest) to 10 (maximal) (11).

**Strength Tests.** Subjects were tested at different ranges of speed and different types of muscular contractions: concentric force (60 and 120°·s⁻¹), eccentric force (120°·s⁻¹), and isometric force (5 seconds at 60°) on knee flexors with an isokinetic dynamometer (Con-Trex MJ; CMV AG). Subjects were comfortably seated on the dynamometer chair, with the hip joint at 75°. Full extension of the leg was considered as 0° for dynamic tests (range of motion 0–90°). The distal shin pad of the dynamometer was attached 3–4 cm proximal to the lateral malleolus by using a strap. During thigh muscle contractions, to minimize extraneous body movements,
straps were applied across the chest, pelvis, and midthigh. The alignment between the dynamometer rotational axis and the knee joint rotation axis (lateral femoral condyle) was checked at the beginning of each trial. Gravity effect torque was recorded for each subject throughout the range of motion, and this was used to correct torque measurements during all tests. Strength was tested immediately after the exercise inducing muscle damage (post), immediately after the recovery session (20 hours), and 24 and 48 hours postexercise.

**Creatine Kinase.** Blood samples were taken from 32-μl fingertip capillary punctures to assess plasma creatine kinase concentrations (CK). Blood was placed on a measurement strip, and analyses were performed using a Reflotron (Roche Diagnostics). The Reflotron was calibrated according to the manufacturer’s recommendations. A previous study by Hörder et al. (18) showed a between-day coefficient of variation (CV) of 4.2% for creatine kinase measures using the Reflotron. In the same study, comparison between the Reflotron and other assays showed a correlation $r = 0.994$. Plasma CK were measured before the exercise, before the recovery session (20 hours), and 24 and 48 hours postexercise.

**Muscle Soreness.** Subjects were asked to rate their level of hamstring soreness using a Likert scale from 0 (not sore) to 10 (very very sore) (36). Muscle soreness was rated before the exercise (pre), immediately after the exercise (post), before the recovery session (20 hours), and 24 and 48 hours after the exercise.

**Figure 3.** Evolution of eccentric force at 120° s$^{-1}$ and isometric force at 60° in the passive and active recovery conditions at baseline (pre), postexercise (post), and 20, 24, and 48 hours after the exercise inducing muscle damage. ES = effect size between active and passive recovery.
the greater trochanter and the external femoral condyle. The skin was marked with a semipermanent marker for consistency on subsequent days. Thigh circumference was assessed immediately before exercise, immediately post-exercise, immediately after the recovery session (20 hours), and 24 and 48 hours after the exercise. Vaile et al. (38) showed a good reliability for these measurements with an intraclass correlation coefficient (ICC) = 1.00 and a CV = 0.1%.

Recovery Sessions. Recovery sessions took place the day after the exercise in the morning (between 8:30 and 10:00 AM). The active recovery session corresponded to a strength training session made up of 5 upper-limb exercises in the following order: bench press, lat pull-down, seated cable rows, biceps curl, and triceps pushdown. One repetition maximum (1RM) was defined by the maximal mass the subject was able to move on 1 repetition. The 1RM testing took place during the baseline tests. Subjects performed the 1RM test twice, and the best result was considered as the baseline value. For each exercise, subjects performed 3 sets at 70% of 1RM until exhaustion interspersed by 1-minute recovery. During passive recovery session, subjects were seated in a room for 15 minutes. Passive recovery duration was defined before the experimentation. As the upper-body strength training session lasted for 15 minutes, the duration of passive recovery was standardized according to the duration of the strength training session.

Statistical Analyses

Data are presented as mean ± SD. We calculated the CV, ICC, 90% confidence intervals (CIs), and typical error (TE) (17). Values for force, CMJ-1L, and power output were normalized to 100%. Statistical power of the different force measurements ranged between 0.79 and 0.04. Normality of the data was checked with the Shapiro-Wilk test. The effect of time and condition on the dependent variables—strength, creatine kinase, soreness, CMJ, power, thigh circumference—was analyzed using a 2-way analysis of variance with repeated measures. If the F-value was significant, Bonferroni post hoc test was applied. Cohen’s d corrected by Hopkins was calculated to determine the effect size (ES) that was interpreted as follows: 0 ≤ ES ≤
0.2 = trivial, 0.2 < ES ≤ 0.6 = small, 0.6 < ES ≤ 1.2 = moderate, 1.2 < ES ≤ 2.0 = large, 2.0 < ES ≤ 4.0 = very large, and >4.0 = nearly perfect (16).

**RESULTS**

**Time × Condition Effect**

There was no significant effect of interaction between time and condition for each outcome measured: concentric force at 60°·s⁻¹ (p = 0.45); concentric force at 120°·s⁻¹ (p = 0.94); eccentric force at 120°·s⁻¹ (p = 0.94); isometric force at 60° (p = 0.94); CMJ-1L (p = 0.99); mean power output during single-leg sprint (p = 0.98); CK (p = 0.61); thigh circumference at 1/3 (p = 0.99), 2/3 (p = 0.99), and 1/2 (p = 0.99); and muscle soreness (p = 0.67).

**Condition Effect**

Results showed a moderate effect of condition 48 hours after the exercise inducing muscle damage for concentric force at 60°·s⁻¹ (ES = 0.65; 90% CI = −0.06 to 1.32), whereas trivial to small effect sizes were observed before, immediately after, and 20, 24 hours after the exercise inducing muscle damage (Figure 2). Trivial to small effects of condition were observed before, immediately after, and 20, 24, and 48 hours for the other outcomes: concentric force at 120°·s⁻¹, eccentric force at 120°·s⁻¹, isometric force at 60°, jump height during CMJ-1L, mean power output.
<table>
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<th>Outcome</th>
<th>Condition</th>
<th>Post</th>
<th>20 h</th>
<th>24 h</th>
<th>48 h</th>
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<td>Concentric force 60°·s⁻¹ (N·m⁻¹)</td>
<td>PAS</td>
<td>ES = 1.16 (90%)</td>
<td>ES = 0 (90%)</td>
<td>ES = 0.24 (90%)</td>
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<td>ES = 1.16 (90%)</td>
<td>ES = 0.17 (90%)</td>
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<td>Eccentric force 120°·s⁻¹ (N·m⁻¹)</td>
<td>PAS</td>
<td>ES = 1.41 (90%)</td>
<td>ES = 1.96 (90%)</td>
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<td></td>
<td>ACT</td>
<td>ES = 1.15 (90%)</td>
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<td>Isometric force 60° (N)</td>
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<td>ES = 2.42 (90%)</td>
<td>ES = 1.73 (90%)</td>
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<td>ES = 1.41 (90%)</td>
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<td>CMJ-1L (cm)</td>
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<td>ES = -0.12 (90%)</td>
<td>ES = 2 (90%)</td>
<td>ES = 2 (90%)</td>
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<tr>
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<td>ES = 2 (90%)</td>
<td>ES = 2 (90%)</td>
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<tr>
<td>MPO (W)</td>
<td>PAS</td>
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<td>ES = 2 (90%)</td>
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<tr>
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<td>ES = 2 (90%)</td>
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</tr>
<tr>
<td>Soreness (Arbitrary units)</td>
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<td>ES = 2 (90%)</td>
<td>ES = 2 (90%)</td>
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<tr>
<td>CK (U·L⁻¹)</td>
<td>PAS</td>
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<td>ES = 2 (90%)</td>
<td>ES = 2 (90%)</td>
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<tr>
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*PAS = passive recovery; ES = effect size; CI = confidence interval; ACT = active recovery; CMJ-1L = single-leg countermovement jump; CK = creatine kinase concentration; N/A = not available; MPO = mean power output.
output during single-leg sprint, CK, and soreness. All the results for condition effect are presented in Figures 2–6.

For thigh circumference, small effect of condition was observed for 1/3 (ES 48 vs. 48 hours = 0.31; 90% CI = -0.37 to 0.98), 2/3 (ES 48 vs. 48 hours = 0.4; 90% CI = -0.29 to 1.06), and 1/2 (ES 48 vs. 48 hours = 0.48; 90% CI = -0.21 to 1.15).

**Time Effect**
Results of time effect for force, jump height, power, soreness, and CK before, immediately after, and 20, 24, and 48 hours after the exercise inducing muscle damage are presented in Table 1.

For thigh circumference, results show trivial effects after the exercise inducing muscle damage in the control condition at 1/3 (pre vs. 48 hours: 56.1 ± 1.9 vs. 55.9 ± 1.8, ES = 0.08; 90% CI = -0.6 to 0.75), 2/3 (pre vs. 48 hours: 46.9 ± 1.9 vs. 46.7 ± 2.1, ES = 0.1; 90% CI = -0.58 to 0.77), and 1/2 (pre vs. 48 hours: 52.9 ± 1.9 vs. 53 ± 1.8, ES = -0.04; 90% CI = -0.71 to 0.63).

In the experimental condition, for thigh circumference, results show trivial effects after the exercise inducing muscle damage at 1/3 (pre vs. 48 hours: 57.1 ± 2.7 vs. 56.6 ± 2.4, ES = 0.19; 90% CI = -0.5 to 0.87), 2/3 (pre vs. 48 hours: 48 ± 3.9 vs. 47.7 ± 3.2, ES = 0.07; 90% CI = -0.62 to 0.75), and 1/2 (pre vs. 48 hours: 53.9 ± 2.3 vs. 54.1 ± 2.9, ES = -0.08; 90% CI = -0.77 to 0.61).

**Rate of Perceived Exertion**
Mean value of RPE collected after the exercise inducing muscle damage in the active recovery condition (6.4 ± 1) was not significantly different from mean value in the passive recovery condition (6.1 ± 1.3) (*p* = 0.257; ES: 0.29; 90% CI = -0.40 to 0.95).

**Reliability**
Interday test-retest reliability for strength and power showed good reliability of the outcomes (Table 2). Isometric strength, CMJ-1L, and mean power output had the lowest CV and the highest ICC (Table 2). Intraclass correlation coefficient, TE, and CV are criteria for reliability. Reliability is generally considered high when ICC is above 0.90 (39) and good when ICC is above 0.75 (9). A good level of reliability was reported for concentric force at 60°·s⁻¹ (ICC = 0.84) and eccentric force at 120°·s⁻¹ (ICC = 0.86). Reliability for isometric force at 60° (ICC = 0.97), CMJ-1L (ICC = 0.98), and 1-leg power on treadmill (ICC = 0.94) was high. For concentric force at 120°·s⁻¹ (ICC = 0.75), reliability was low. TE was low for all the tests, which indicate a good reliability as the smaller the TE the more reliable the measurements (2). A CV is generally considered high when it is above 10% (2). For concentric force at 60°·s⁻¹ (CV = 12.5%), concentric force at 120°·s⁻¹ (CV = 11.5%), and eccentric force at 120°·s⁻¹ (CV = 11.4%), CV was high. For isometric force at 60° (CV = 6%), CMJ-1L (CV = 6.3%), and 1-leg power on treadmill (CV = 7.9%), CV was low.


DISCUSSION

The purpose of this study was to investigate the effects of a strength training session after an exercise inducing muscle damage on performance recovery. According to theoretical data, we hypothesized that a strength training session would accelerate the time to fully recover. The results of this study did not confirm this hypothesis. However, for concentric strength at a speed of $60^\circ \cdot s^{-1}$, a moderate effect of condition was found 48 hours after the eccentric exercise. But, examining the CI shows that it includes 0 and having CIs that do not cross 0 have the most clinical significance (30). No differences were found between control and experimental conditions for the other outcomes. It should also be noted that the strength training session did not delay the recovery kinetics.

Concerning the time effect, eccentric exercise is known to induce muscle damage during several days leading to a performance decrease across time (19). In the present study, force performance showed a moderate to large decrease after exercise in passive and active recovery conditions. These results are consistent with other studies that showed a force decrease after eccentric exercise (27). As neuromuscular function is a good indicator of muscle damage (40), these results confirm the effectiveness of the knee flexors eccentric exercise on inducing muscle damage.

Regarding the condition effect, results showed a moderate effect in favor of the active recovery condition for concentric force at $60^\circ \cdot s^{-1}$ 48 hours after exercise. Trivial to small effects of condition were found for concentric force at $120^\circ \cdot s^{-1}$, eccentric force at $120^\circ \cdot s^{-1}$, and isometric force at $60^\circ$ (Table 2). The results obtained also showed that concentric force at $60^\circ \cdot s^{-1}$ returned to baseline values 20 and 24 hours after the exercise inducing muscle damage in both conditions (active and passive recovery), but 48 hours after the exercise, concentric force at $60^\circ \cdot s^{-1}$ decreased only in the passive recovery condition. Studies showed that after a 1-limb exercise, cross-adaptations occur (35). The rate of recovery in the contralateral limb is faster after an exercise on a single limb. In this context, and to avoid the repeated bout effect in the present study, half of the subjects performed the active recovery first and the passive recovery in second time and vice versa. As such, it is unlikely that the present results can be explained by the influence of repeated bout effect. This result may be explained by the increase of hormone concentrations induced by the strength session (20,32). The natural process of muscular regeneration starts immediately after an eccentric exercise, and it is characterized by satellite cell proliferation and activation (8,14). Growth hormone, IGF-1, and testosterone are implicated in this process by stimulating proliferation, activation, and fusion of satellite cells with the injured fibers (5,8,14). Even if there is a peak of hormonal concentrations immediately after an eccentric exercise, this hormonal secretion is limited in time and hormonal concentrations values return to baseline after several hours (22). It could be suggested that performing a strength session such as the one performed in the present study the day after an eccentric exercise maintains the muscles in an anabolic condition that accelerates the rate of muscle regeneration and consequently recovery kinetics (37). Results of this study demonstrate that implementing a strength training session the day after an exercise has a moderate effect on recovery kinetics for concentric force at $60^\circ \cdot s^{-1}$ 48 hours after the exercise. The strength training session was not detrimental for recovery of the other outcomes measured. One of the hypotheses that may explain these results is that the secretion of hormones induced by the strength training session led to a regeneration process. In this study it was not possible to confirm this because of the absence of hormonal blood measures.

After an exercise inducing muscle damage, an inflammatory process takes place in the muscle with the attraction of neutrophils within the first 24 hours and macrophages after 24 hours (34). This attraction, associated with other processes, is linked with damage in the muscle (34). Combination of these 2 mechanisms may explain the evolution of force observed in this study. It could be hypothesized that within the 24 hours after the exercise, leucocytes accumulation was not enough to induce muscle damage and, consequently, a loss of force. Forty-eight hours after the exercise, the accumulation of leucocytes was so great that the damage in the muscle led to a high level of muscle damage and consequently a force decrease in the passive recovery condition. To explain the difference between conditions 48 hours postexercise, it could also be postulated that some muscle fibers were sufficiently regenerated to help in improving maximal strength. In contrast, in the passive recovery condition, only the fibers that were not injured or those with minor injury were able to produce a force.

A moderate effect of condition 48 hours after exercise was found only for concentric force at $60^\circ \cdot s^{-1}$ but not for isometric, eccentric, and fast concentric force. These results may be the consequence of differences in recruitment patterns in muscle fibers. When performing an eccentric exercise, fiber-type muscle damage occurs with a higher level of damage in type II fibers (12). Moreover, Cermak et al. (6) showed that, after a knee extension exercise, satellite cell proliferation was increased in type II fibers but not in type I fibers meaning that type I fibers were less injured than type II fibers. Results of this study are consistent with those of Fridén et al. (13), who found a faster recovery rate for force at slow speeds in comparison with force at fast speeds or isometric force. The fact that concentric force at $60^\circ \cdot s^{-1}$ was the slowest force can explain why a return to baseline value was observed in both conditions at 20 and 24 hours postexercise. To explain the difference between conditions 48 hours postexercise, it could be postulated that some muscle fibers were sufficiently regenerated to help in improving maximal strength. In contrast, in the passive recovery condition, only the fibers not injured or with minor injury only were able to produce a force.
Countermovement jump and sprint test are used to assess power performance of the lower limb. As hamstrings are involved in this kind of movement (15, 29), it was hypothesized that a knee flexors eccentric exercise would decrease power performance. Trivial to large increases of performance showed that the exercise inducing muscle damage was not sufficient to induce a loss of power. A moderate effect of condition was found in favor of the control condition 24 hours after exercise showing no effect of the strength training session on the recovery of these parameters.

Consistent with other studies, muscle soreness was increased continuously from baseline to 48 hours for both conditions (28). When comparing passive and active recovery condition, a small effect of condition was detected at each time point. Muscle soreness is an indirect and delayed marker of muscle damage that may not always occur after an exercise (28). The magnitude of muscle strength decrease is influenced by exercise intensity, making this criterion a good indirect marker of muscle damage (28, 40). It is possible that muscle damage persists in the absence of muscle soreness (28). The recovery strategy used in this study did not have a positive effect on reducing muscle soreness.

In some studies evaluating muscle damage, CK were increased after exercise (10), which is different from the results found in this study. Because of the high intensity of the exercise, an increase in CK activity was expected, but surprisingly no change in blood CK was observed across time after the exercise inducing muscle damage. These results can be explained by the high variability found between subjects. As subjects in this study were familiarized with hamstring eccentric contractions, one can suppose that their CK was lower than if they were untrained subjects and not familiarized with hamstring eccentric contractions. The level of creatine kinase after an exercise has been shown to be higher in untrained subjects in comparison with trained subjects (4). Thigh circumference represents the edema amplitude in muscle after exercise inducing muscle damage. In this study, neither time nor condition affected this parameter. These results are consistent with other studies in which no effect of time was observed after an exercise inducing muscle damage on knee extensors muscle (19). The exercise inducing muscle damage in this study was not sufficient to induce edema in the muscle.

This experimental research presents some limitations. First, blood hormone concentrations before and after the strength training session were not measured. With this measure, the mechanisms underpinning the results would have been explained more precisely. Recovery kinetics were evaluated within 48 hours in this study, and using other recovery strategies have been shown to be effective 72 hours or more after exercise (38). Evaluating performance outcomes may be more relevant across 72 hours or more to have more possibilities to observe an effect when one exists. Subjects recruited for this study were physically active but not familiarized with this kind of strength session. They have been practicing strength training twice a week but with lower loads than those used in this study. Because of their physical activity, the familiarization with eccentric contractions may have attenuated the repeated bout effect. Strength-trained subjects are able to secrete higher hormonal concentrations after a strength session in comparison with subjects who are not accustomed to this type of training (21). These data indicate that strength-trained subjects would have secreted higher hormones and consequently could have recovered faster than untrained subjects. Even if the results of this study showed a moderate effect of condition on performance recovery kinetics for slow concentric force, the CI included 0. When CIs do not include 0, the results obtained are more relevant, which is not the case in this study (30). The blood samples were not run in duplicates or triplicates to calculate the CV of creatine kinase. Having these data would have given precise information of variability for this group of subjects. The CIs for many of the outcomes were very large and span all the levels of magnitude (harmful, beneficial, and trivial), which characterize an unclear result because of a small sample size (30). Moreover, the levels of statistical power for condition effect for concentric force at 60°·s⁻¹ (power = 0.58), concentric force at 120°·s⁻¹ (power = 0.03), eccentric force at 120°·s⁻¹ (power = 0.06), and isometric force at 60° (power = 0.24) were low, indicating that the number of subjects was small.

**Practical Applications**

This study showed that performing a strength training session after an exercise inducing muscle damage can influence subsequent performance of concentric force at 60°·s⁻¹ 48 hours postexercise. Although there were no additional beneficial effects on faster concentric force, eccentric force, or isometric force, the addition of an upper-body strength training session the day after muscle-damaging activity does not negatively affect the recovery kinetics. This may have implications for optimizing limited time available for training during the week, with the addition of upper-body strength training the day after a competition when traditionally only nonexhausting recovery strategies are used (e.g., water therapy, jogging, bike).

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