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Protection Against Muscle Damage Following Fifty Drop Jumps Conferred by Ten Drop Jumps

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Abstract. Miyama, M., and K. Nosaka. Protection against muscle damage following fifty drop jumps conferred by ten drop jumps. *J. Strength Cond. Res. 21(4):1087–1092. 2007.*—This study investigated whether 10 drop jumps (DJs) would confer protective effect against muscle damage and soreness in a subsequent bout of 50 DJs. Sixteen men were randomly placed into either a group performing 1 set of 10 DJs followed by 5 sets of 10 DJs (10–50, $n = 8$) or another group performing 2 bouts of 5 sets of 10 DJs (50–50, $n = 8$) separated by 2 weeks. The DJs were performed from a box height of 0.6 m, with a 10-second interval between jumps and a 1-minute rest between sets. Jump height, peak vertical ground reaction force, ground contact time, and heart rate during DJs were measured, and blood lactate concentration was assessed before and immediately after DJs. Changes in maximal isometric (ISO) and isokinetic concentric torque (CON), vertical jump, muscle soreness, and plasma creatine kinase activity before, immediately after, and at 1, 24, 48, and 72 hours following exercise were compared between groups for the first and second bouts and between the bouts by a 2-way repeated-measures analysis of variance. Changes in ISO, CON, vertical jump, and muscle soreness were significantly ($p < 0.05$) smaller for 10 DJs compared with 50 DJs; however, no significant differences in the measures between groups were evident following the second bout. The changes in the measures following 50 DJs in the 10–50 group were significantly ($p < 0.05$) smaller than those following the first bout of the 50–50 group. These results suggest that 10 DJs and 50 DJs conferred the same magnitude of protective effect against muscle damage by 50 DJs.

Key Words. repeated bout effect, isometric torque, vertical jump, creatine kinase, muscle soreness, ground reaction force

Introduction

A drop jump (DJ) is a typical plyometric or stretch-shortening cycle exercise and is widely used as an effective training method to improve jump performance and power (1, 18). It has been shown that repetitive DJs result in severe muscle soreness and a prolonged loss of muscle function in the studies using untrained subjects (10, 11, 13). This may not be the case for strength-trained athletes, but it should be considered how to introduce DJs or other types of plyometric exercises to athletes for the beginning of training season. However, limited information is available as to optimal intensity, frequency, and recovery time between DJ training sessions, and a strategy to minimize potential muscle damage in DJ training is not well documented.

It is known that a single bout of eccentric exercise confers protection against muscle damage following subsequent bouts of the same or more demanding eccentric exercise (6, 9). This phenomenon, often referred to as the repeated bout effect, is characterized by a faster recovery of muscle function, a smaller restriction in joint range of motion, a reduction in swelling and muscle soreness, and a smaller increase in muscle proteins in the blood after repeated exercise bouts (6). Miyama and Nosaka (11) showed that an initial bout of 50 DJs attenuated changes in maximal isometric force, vertical jump performance, muscle soreness, and plasma creatine kinase activity after the same exercise performed 8 weeks later. It has been reported that a reduced number of eccentric muscle actions still confers protective effect against muscle damage induced by a larger number of eccentric actions for the elbow flexors and knee extensors (2, 7, 15); however, it is not known if this is also the case for DJ exercise.

It was hypothesized that a small number of DJs (i.e., 10) resulting in minor damage could induce protective effect against a larger number of DJs, such as 50, which was reported in the previous study (11) to result in severe muscle soreness and a prolonged impairment of muscle function. To test the hypothesis, the present study compared 10 DJs to 50 DJs for changes in indirect markers of muscle damage after exercise and for their effects on the subsequent bout of 50 DJs performed 2 weeks later.

Methods

Experimental Approach to the Problem

To investigate the magnitude of protective effect conferred by 10 DJs against 50 DJs, 2 groups of subjects were compared. One group performed 10 DJs followed 2 weeks later by 50 DJs, and the other group performed 2 bouts of 50 DJs separated by 2 weeks on the assumption that this group would show a significant protective effect based on the previous study (11). Changes in several indirect markers of muscle damage, such as maximal isometric and dynamic torque of the knee extensors, vertical jump height, muscle soreness, and plasma creatine kinase (CK) activity following the DJ exercise, were compared between groups and between bouts. Jump height (DJ height), peak vertical ground reaction force (peak VGRF), ground contact time, heart rate (HR) during the DJ exercise, and changes in blood lactate concentration were also measured. Thus, the independent variables were the number of DJs for the first bout, and the dependent variables were maximal isometric and dynamic torque of the knee extensors, vertical jump height, muscle soreness, and plasma CK activity.

Subjects

This study was approved by the Institutional Ethics Human Research Committee. Sixteen men who had little or no experience in resistance training participated in this study after giving written informed consent, consistent

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with the principles outlined in the Declaration of Helsinki. The main reason for using "untrained" subjects in the present study was that the protective effect conferred by the 10 DJs, if any, would be better demonstrated by untrained subjects, since trained subjects would have obtained adaptation to DJs from their daily training. It was also the reason that recruiting homogeneous trained subjects was more difficult than recruiting "untrained" subjects since we thought that the results would be affected greatly by the training that the subjects had been performing and how much plyometric exercises they had experienced in the training.

Their mean (± *SD*) age, height, body weight, and percentage of body fat were 21.1 ± 1.1 years, 174.0 ± 7.2 cm, 65.1 ± 8.0 kg, and 15.8 ± 3.7%, respectively. The subjects were placed randomly into 1 of the 2 groups: 10–50 group (n = 8) and 50–50 group (n = 8). The subjects in the 10–50 group performed 1 set of 10 DJs for the first bout followed 2 weeks later by 5 sets of 10 DJs for the second bout. The 50–50 group (n = 8) performed 2 bouts of 5 sets of 10 DJs separated by 2 weeks. No significant differences between groups existed for the physical characteristics such as age, height, percent body fat, and maximal isometric and dynamic torque of the knee extensors. All subjects were free from any musculoskeletal disorders and were requested not to perform any vigorous physical activities or unaccustomed exercises during the experimental period. Subjects were asked to abstain from any medicine and dietary supplements during the experimental period.

Exercise

Subjects performed DJs from a box height of 0.6 m to a wood (oak)-surfaced force platform (TR61750-103, Sogokeiso Inc., Tokyo, Japan). This height was used in a previous study (8, 10, 11), and we had confirmed that "untrained" subjects were able to perform repetitive DJs from this height appropriately and safely from this height. To standardize the influence of shoes, the same kind of shoes (609, Achilles Spalding, Tokyo, Japan) were prepared, and each subject chose a comfortable size, and the same shoes were worn for both bouts. Subjects were asked to jump upward maximally immediately after landing on the box and landed on the surface again after the vertical jump, then climbed 4 steps onto the box for the next DJ. This was repeated 10 times with a 10-second interval between jumps and a 1-minute rest between sets where 5 sets were performed. The investigators carefully supervised the exercise to check if the DJs were adequately performed and to eliminate a risk of unexpected injury.

Force data from the force plate were amplified by a strain amplifier (AS2102, NEC San-ei, Tokyo, Japan) and recorded using a Power Lab system (Power Lab, AD Instruments, Castle Hill, Australia) connected to a computer (Macintosh G4, Apple Inc., Tokyo, Japan). The sampling frequency was 100 Hz. Using the force data, DJ height, peak VGRF, and ground contact time were analyzed for each jump by a software program of the Power Lab system. The DJ height was calculated from the flight time that was measured as the period between takeoff and subsequent landing from the jump (12). The peak VGRF had 2 phases, and both were measured; the first peak was seen immediately after landing from the box and the second peak at landing after the jump. The ground contact time was defined as the period from the initial landing on the force plate to the takeoff (12).

Heart rate was monitored by a Polar HR monitor (Vantage XL, Polar Electro, Kempele, Finland), and the values at 1 minute before the exercise and immediately after each set of DJ exercises were recorded. Blood lactate concentration was measured by a Biosen 5010 (EKF Industrie, Elektronik GmbH, Barleben, Germany) by obtaining a blood sample (40 μl) from the fingertip with a heparin-coated capillary tube. Blood lactate concentration was measured before and immediately after the exercise.

Criterion Measures of Muscle Damage

This study used indirect markers of muscle damage that have been used in previous studies (2, 7, 10, 11, 15) to examine the extent of muscle damage. The markers included muscle function tests (maximal isometric and dynamic torque of the knee extensors, vertical jump height), muscle soreness, and plasma CK activity. Maximal isometric and dynamic torque of the knee extensors, vertical jump height, and muscle soreness were measured before, immediately after, and at 1, 24, 48, and 72 hours following exercise. Plasma CK activity was assessed before and at 24 and 48 hours after exercise.

The test-retest reliability of the criterion measures had been examined in our previous study (10, 11) and the intraclass correlation coefficient (R) values for the measures were above 0.8.

Maximal Isometric and Dynamic Torque of the Knee Extensors. Maximal isometric (ISO) and isokinetic concentric torque (CON) were measured by an isokinetic dynamometer (CON-TREX MJ, CMV AG, Zürich, Switzerland); ISO was measured 3 times for 3 seconds at a knee joint angle of 70° (1.2 rad) (0° = full extension) with a 30-second rest between attempts, and CON was measured 3 times at 3 different velocities—$90°\cdot s^{-1}$ (1.57 $rad\cdot s^{-1}$), $180°\cdot s^{-1}$ (3.14 $rad\cdot s^{-1}$), and $300°\cdot s^{-1}$ (5.24 $rad\cdot s^{-1}$)—and the range of motion of the knee joint was from 80° (1.40 rad) to 10° (0.17 rad). The mean value of the 3 measurements was used for further analysis.

Vertical Jump. Two types of vertical jumps were measured: a squat jump (SJ) and a countermovement jump (CMJ), using a vertical jump meter (T.K.K.5106 Jump MD, Takei Scientific Instruments Co. Ltd., Tokyo, Japan). For the SJ, the subject was asked to hold a half-squatted position (the knee joint angle approximately 90°, 1.57 rad) for 2 seconds and jump as high as possible after a verbal command of "go" without using a countermovement and keeping his hands on his waist the whole time. The CMJ started from a standing position, and the subject was allowed to use a countermovement to jump as high as possible on the verbal command "go" while keeping his hands on his waist the whole time (3). Each test was performed twice, and the mean value of the 2 measurements was used for the analysis.

Muscle Soreness. A visual analog scale (VAS) consisting of a 100-mm line with "no pain" on one end (0) and "extremely painful" on the other end (100) was used to evaluate muscle soreness on palpation of the belly of the knee extensors (SOR-Pal) and during a squat movement (SOR-Squat). For the SOR-Pal, an investigator palpated a marked site on the right knee extensors using his palm while a subject was sitting upright on a mat with both legs straight and relaxed. The same investigator assessed the muscle soreness for all time points for all subjects, and the pressure applied to the muscle was kept as consistent as possible. The SOR-Squat was assessed when a subject was slowly bending his knee joints to a half-squatted position (90°, 1.57 rad) from a standing position, and the subject rated the pain felt during the movement.

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Plasma CK Activity. Blood was taken from the fingertip, and 34 μl of blood were loaded to a stick of a Reflotron S System (Roche Diagnostics, Tokyo, Japan). The normal reference ranges of plasma CK activity were 24–195 $IU \cdot L^{-1}$ for this method.

Statistical Analyses

Changes in the criterion measures over time after the first and second bout were compared between groups as well as between bouts for each group by a 2-way repeated-measures analysis of variance (ANOVA). The first bout of 50 DJs performed by the 50–50 group and the second bout of 50 DJs by the 10–50 group were also compared by a 2-way repeated-measures ANOVA. Changes in the criterion measures from baseline were analyzed by a 1-way ANOVA. When the ANOVA found a significant interaction effect, a Tukey's post hoc test was used to compare means. Statistical significance was set at $p < 0.05$. Data are presented as means ± *SEM* unless otherwise stated.

RESULTS

Drop Jump Height

Drop jump height did not change significantly during exercise for both 10 DJs and 50 DJs. The mean (± *SEM*) DJ height of the first and second bout of DJs was 0.36 ± 0.01 m and 0.34 ± 0.01 m for the 10–50 group and 0.37 ± 0.01 m and 0.36 ± 0.004 m for the 50–50 group. No significant difference was evident between bouts and between groups.

Peak Vertical Ground Reaction Force

The peak VGRF recorded at the initial contact to the force plate was 280.7 ± 6.5 N, which was 4.0–4.6 times the body weight throughout the exercise, and did not change significantly during exercise. The VGRF at landing after jump was 331.0 ± 8.1 N, which was 4.8–5.2 times the body weight throughout the exercise. No significant differences were found between groups or between bouts.

Ground Contact Time

The ground reaction force did not change significantly during 10 DJs (585 ± 0.03 ms); however, it increased significantly from the first set (549 ± 0.03 ms) to the fifth set (618 ± 0.04 ms) during 50 DJs (Figure 1). No significant difference in the changes in ground contact time during 50 DJs was evident between bouts for the 50–50 group or between groups.

Heart Rate

Heart rate increased significantly after each set of DJs from the prevalue (79.8 ± 2.8 $b \cdot min^{-1}$) and HR was 145.6 ± 7.7 $b \cdot min^{-1}$ immediately after 10 DJs and 162.6 ± 5.0 $b \cdot min^{-1}$ after 50 DJs for the first bout. After the second bout, HR increased similarly to that observed in the first bout of the 50–50 group, and no significant difference was observed between groups.

Blood Lactate Concentration

The pre-exercise blood lactate concentration was 2.5 ± 0.2 $mmol \cdot L^{-1}$ for the 10–50 group and 2.2 ± 0.1 $mmol \cdot L^{-1}$ for the 50–50 group, without a significant difference between groups and between bouts. Blood lactate concentration increased significantly to 3.1 ± 0.2 $mmol \cdot L^{-1}$ (10–50 group) and 3.5 ± 0.4 $mmol \cdot L^{-1}$ (50–50 group) after the first bout, and no significant difference was evident between groups. Changes in lactate after the second bout were not significantly different from those after the first bout, and no significant difference between groups was found.

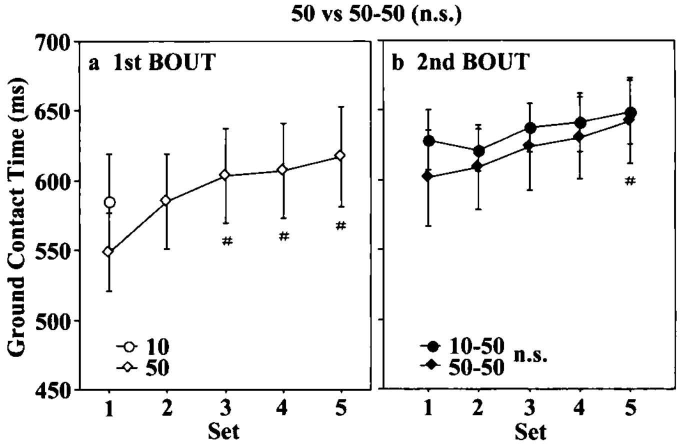

FIGURE 1. Changes in ground contact time during drop jumps (DJs) from the first to fifth set for the first bout (a: 10 DJs, 50 DJs) and the second bout (b: 50 DJs of the 10–50 group, 50 DJs of the 50–50 group). The results of comparison between the first and second bouts for the 50–50 group are also shown on the top of the graphs. # = a significant difference from the pre-exercise value; n.s. = not significant.

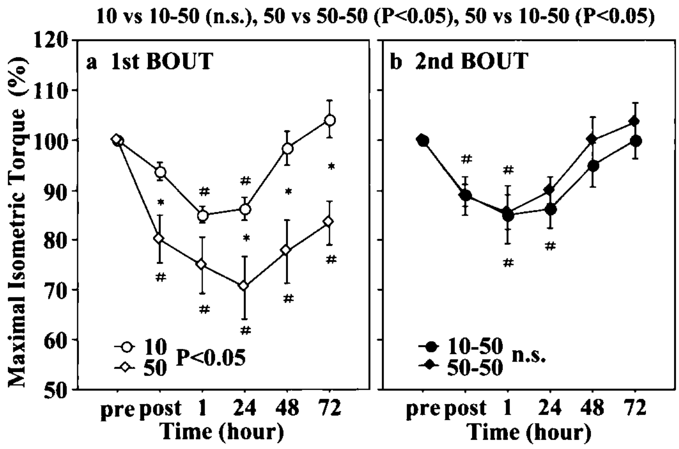

FIGURE 2. Normalized changes in maximal isometric torque from the pre-exercise value (100%) immediately before (pre) and after (post) and at 1, 24, 48, and 72 hours after exercise for the first bout (a: 10 drop jumps [DJs], 50 DJs) and the second bout (b: 50 DJs of the 10–50 group, 50 DJs of the 50–50 group). The results of comparison between the first and second bouts for the 10–50 group and the 50–50 group and the first bout of the 50–50 group and second bout of the 10–50 group are also shown on the top of the graphs. * = a significant ($p < 0.05$) difference between groups or bouts; # = a significant difference from the pre-exercise value; n.s. = not significant.

Maximal Isometric and Isokinetic Concentric Torque

No significant differences between groups existed for the pre-exercise ISO of the first (10–50: 182.2 ± 12.2 N·m; 50–50: 191.7 ± 25.5 N·m) and second bouts (10–50: 197.9 ± 12.2 N·m; 50–50: 203.6 ± 25.8 N·m). Normalized changes in ISO are shown in Figure 2; ISO decreased significantly after 10 DJs and 50 DJs, but the decrease was significantly smaller for 10 DJs than 50 DJs, and ISO recovered to the baseline at 48 hours postexercise for 10 DJs, but this was not the case for 50 DJs. After the second bout, changes in ISO were not significantly different between groups. When comparing the changes in ISO after

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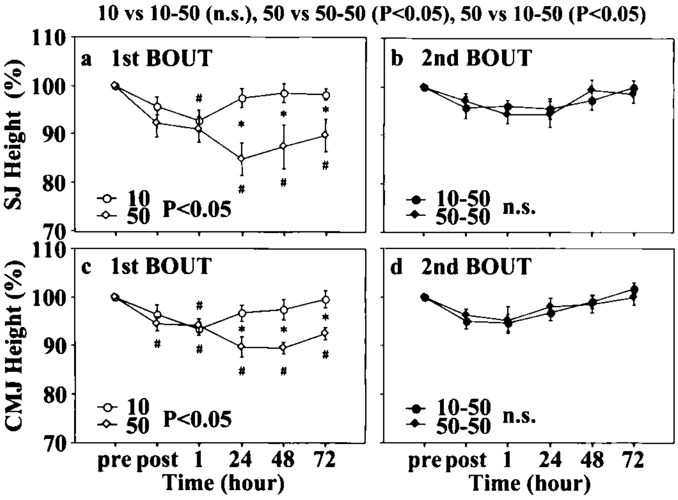

FIGURE 3. Normalized changes in squat jump (a, b) and countermovement jump (c, d) height from the pre-exercise value (100%) immediately before (pre) and after (post) and at 1, 24, 48, and 72 hours after exercise for the first bout (a: 10 drop jumps [DJs], 50 DJs) and the second bout (b: 50 DJs of the 10–50 group, 50 DJs of the 50–50 group). The results of comparison between the first and second bouts for the 10–50 group and the 50–50 group and the first bout of the 50–50 group and second bout of the 10–50 group are also shown on the top of the graphs. * Significant ($p < 0.05$) difference between groups or bouts; # Significant difference from the pre-exercise value; n.s. = not significant; CMJ = countermovement jump.

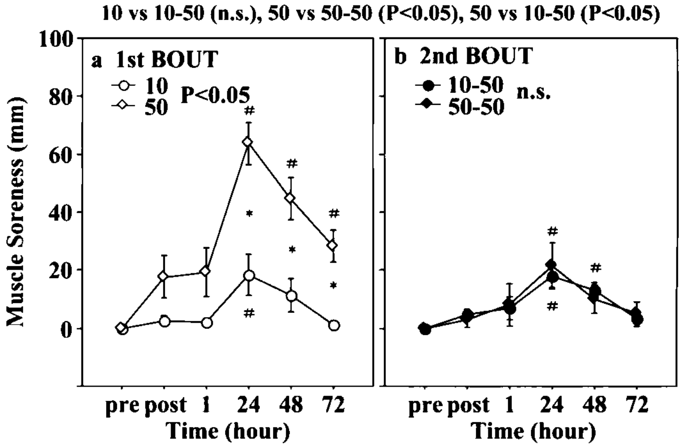

FIGURE 4. Changes in muscle soreness during squat movement immediately before (pre) and after (post) and at 24, 48, and 72 hours after exercise for the first bout (a: 10 drop jumps [DJs], 50 DJs) and the second bout (b: 50 DJs of the 10–50 group, 50 DJs of the 50–50 group). The results of comparison between the first and second bouts for the 10–50 group and the 50–50 group and the first bout of the 50–50 group and second bout of the 10–50 group are also shown on the top of the graphs. * Significant ($p < 0.05$) difference between groups or bouts; # Significant difference from the pre-exercise value; n.s. = not significant.

50 DJs between the first bout of the 50–50 group and the second bout of the 10–50 group, the latter showed a significantly smaller decrease.

No significant differences in the pre-exercise CON of all velocities were evident between groups for the first and second bouts. The pre-exercise value of 90°·s^{-1}, 180°·s^{-1}, and 300°·s^{-1} were 140.5 ± 10.1 N·m, 111.7 ± 8.4 N·m, and 92.4 ± 7.0 N·m for the first bout and 147.6 ± 10.4 N·m, 123.9 ± 8.6 N·m, and 101.6 ± 8.1 N·m for the second bout, respectively. The pre-exercise CON was significantly smaller than ISO, and the faster the velocity, the lower the torque with a significant difference. However, the magnitude of decrease in CON was not significantly different from that of ISO, and no significant differences were evident between the velocities; CON decreased significantly after 10 DJs and 50 DJs, and the magnitude of decrease in CON was greater for 50 DJs than 10 DJs. The reduction in CON after the second bout was not significantly different between groups. The decrease in CON after 50 DJs of the 10–50 group was significantly smaller than the first 50 DJs of the 50–50 group.

Vertical Jump Performance

No significant differences between groups were evident for the SJ (10–50: 0.43 ± 0.01 m; 50–50: 0.45 ± 0.02 m) and CMJ (10–50: 0.49 ± 0.02 m; 50–50: 0.52 ± 0.02 m) before the first bout. Before the second bout, SJ (10–50: 0.42 ± 0.01 m; 50–50: 0.44 ± 0.01 m) and CMJ (10–50: 0.49 ± 0.01 m; 50–50: 0.52 ± 0.01 m) were also not significantly different between groups; CMJ was significantly higher (approximately 15%) than SJ before the first and second bouts. Figure 3 shows normalized changes in SJ and CMJ after exercise. Both SJ and CMJ decreased significantly after DJs, but a significantly larger decrease was observed for 50 DJs compared with 10 DJs. Changes in SJ and CMJ after the second exercise bout were not significantly different between groups. The decrease in SJ and CMJ after 50 DJs of the 10–50 group was significantly smaller than the first 50 DJs of the 50–50 group. The magnitude of change in SJ was not significantly different from that of CMJ.

Muscle Soreness

Muscle soreness developed after exercise, and SOR-Pal and SOR-Squat showed similar values. As shown in Figure 4, SOR-Squat after the first bout was significantly smaller for the 10 DJs than 50 DJs, but no significant difference between bouts existed after the second bout. SOR-Squat after 50 DJs of the 10–50 group was significantly lower than the first 50 DJs of the 50–50 group. This was also the case for SOR-Pal.

Plasma Creatine Kinase Activity

The baseline plasma CK activity was similar between groups and between bouts. Plasma CK activity increased significantly at 24 hours postexercise for both bouts, and no significant difference between groups existed (Figure 5). However, the magnitude of increase in plasma CK activity after the second bout for the 10–50 group was significantly smaller than the first 50 DJs of the 50–50 group.

DISCUSSION

This study investigated the hypothesis that 10 DJs could confer protective effect against muscle damage and soreness induced by 50 DJs. The results supported the hypothesis, showing that the 10 DJs had the same protective effects as the 50 DJs on changes in criterion measures after the subsequent bout of 50 DJs (Figures 2–5). This confirmed previous studies (2, 7, 15) showing that a reduced number of eccentric muscle actions in the initial bout still induced a significant protective effect against muscle damage induced by a larger number of eccentric

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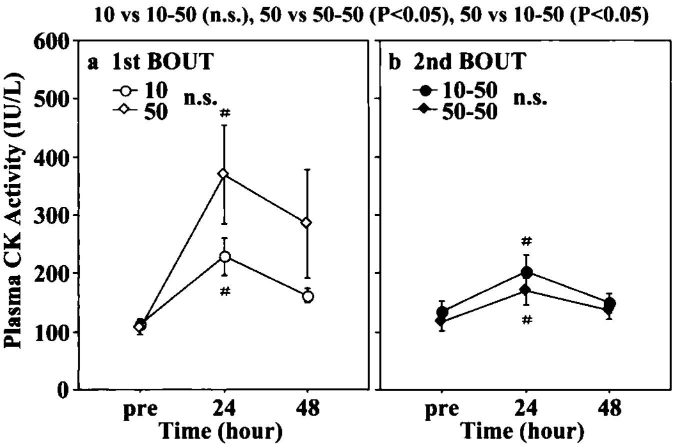

FIGURE 5. Changes in plasma creatine kinase (CK) activity before (pre) and at 24 and 48 hours after exercise for the first bout (a: 10 drop jumps [DJs], 50 DJs) and the second bout (b: 50 DJs of the 10–50 group, 50 DJs of the 50–50 group). The results of comparison between the first and second bouts for the 10–50 group and the 50–50 group and the first bout of the 50–50 group and second bout of the 10–50 group are also shown on the top of the graphs. * Significant ($p < 0.05$) difference between groups or bouts; # Significant difference from the pre-exercise value; n.s. = not significant.

actions. However, this was the first study to show the phenomenon in a DJ exercise, and it is important to note that the level of protection conferred by 10 DJs was similar to that of 50 DJs.

It was reported that 50 DJs resulted in a sustained loss of muscle function, muscle soreness, and increases in plasma CK activity, and the changes in these variables in the present study were similar to those in the previous study (11). It appears that the knee extensors were subjected to eccentric actions at the moment of landing, and these repetitive eccentric muscle actions were a primary cause of muscle damages (11). Compared to 50 DJs, changes in ISO (Figure 2); CON, SJ, and CMJ (Figure 3); and muscle soreness (Figure 4) after 10 DJs were significantly smaller. It is important to note that muscle function recovered to the baseline by 48 hours after 10 DJs, whereas it was still 10–20% lower than the baseline at 72 hours postexercise for 50 DJs. Moreover, muscle soreness was minor after 10 DJs (Figure 4). Because of the large intersubject variability, no significant difference between 10 and 50 DJs was found for changes in plasma CK activity (Figure 5); however, there was a tendency for increases in plasma CK activity to be smaller for 10 DJs than 50 DJs. It is stated that a prolonged strength loss after eccentric exercise is one of the most valid and reliable indirect measures of muscle damage (17). Together with the greater decreases in SJ and CMJ height and greater development of muscle soreness after 50 DJs than 10 DJs, it seems reasonable to state that the 50 DJs induced greater muscle damage than 10 DJs.

It seems that the number of DJs determined the magnitude of changes in the criterion measures. However, it is interesting to note that the magnitude of change in the criterion measures after 10 DJs was not necessarily one-fifth of that after 50 DJs. For example, the maximal change in ISO, CON, vertical jump performance, and plasma CK activity after 10 DJs was approximately 40–60% of that of 50 DJs, and peak muscle soreness after 10 DJs was approximately 25–30% of that of 50 DJs. It seems that the magnitude of muscle damage was not necessarily proportional to the number of DJs performed; DJ height and peak VGRF were consistent throughout 10 DJs and 50 DJs, and no significant differences existed between 10 and 50 DJs. It should be noted that ground contact time increased significantly from the first set to the fifth set for the 50 DJs (Figure 1). It seems likely that the subjects bent their knee joints deeper before jumping vertically toward the end of 50 DJs, which required eccentric muscle actions at longer muscle lengths. It has been shown that the magnitude of eccentric exercise-induced muscle damage is greater when eccentric muscle actions are performed at a long muscle length than an equivalent bout performed at a short muscle length (5, 14). Thus, it may be that 50 DJs generated long muscle length eccentric actions, inducing greater muscle damage than 10 DJs, especially for the 50 DJs performed for the first bout. It is also possible to assume that a larger number of muscle fibers become vulnerable to eccentric actions with an increasing number of DJs because of fatigue and/or accumulated mechanical stress to the fibers. Further study is necessary to examine these speculations.

The most important finding of this study was that 10 DJs were as effective as 50 DJs for conferring the protective effect against 50 DJs performed 2 weeks later. The changes in criterion measures after 50 DJs in the second bout were almost identical between groups (Figures 2–5). Furthermore, the changes in the criterion measures after 50 DJs in the 10–50 group were significantly smaller than those after the first 50 DJs of the 50–50 group. It has been reported that performing an initial bout of eccentric exercise with a relatively smaller number of eccentric actions produces a protective effect against a second bout consisting of larger number of eccentric actions using the elbow flexors (7, 15) or the knee extensors (2). Brown et al. (2) reported that 10, 30, or 50 maximum voluntary eccentric contractions of the knee extensors provided equal protection for a subsequent bout of 50 eccentric contractions performed 3 weeks later.

The underlying mechanisms of the protective effect conferred by a single bout of exercise are still unclear, but it appears that several systems involve in the process (9). These include an increased recruitment of slow motor units, activation of a larger motor unit pool (neural adaptation), increased dynamic and passive muscle stiffness (mechanical adaptation), longitudinal addition of sarcomeres, adaptation in inflammatory response, adaptation to maintain excitation-contraction coupling (cellular adaptation), and others (heat shock proteins, removal of weak sarcomeres or muscle fibers) (9). It may be that many of these adaptations were associated with the protective effect conferred by 10 DJs, but it is difficult to speculate on what had actually taken place after 10 DJs; therefore, this warrants further study to delineate the underlying mechanisms.

It is important for athletes and coaches to be aware of the influence of muscle damage on athletic performance and the time course of recovery from muscle damage that is induced by training and/or athletic events (4). It should be noted that muscle function did not recover within 72 hours after 50 DJs (Figures 2 and 3); however, it recovered to baseline by 48 hours in the subsequent bout. In the present study, untrained subjects were used; therefore, it would appear that recovery of trained athletes after DJs would be faster if they were accustomed to DJs. However, in an early stage of training, it might be possible that recovery from training consisting of DJs takes some days. Thus, a reduced number of DJs may be

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beneficial for them to prepare for a more demanding training protocol. It would be interesting to confirm the results of the present study by using athletes.

In summary, the present study showed that 10 DJs from a box height of 0.6 m induced minor muscle damage that was completely recovered within 2 days and conferred a protective effect against potentially greater muscle damage induced by 50 DJs performed 2 weeks later. When DJ training is designed, if severe muscle damage should be avoided, starting from a small number of DJs should be considered.

PRACTICAL APPLICATIONS

To avoid severe muscle damage induced by eccentric or eccentric-biased exercise, preconditioning of muscles is important, and this can be achieved by a few eccentric actions (2, 15). However, it has not been known if this is the case for DJ exercise. The results of this study showed that 10 DJs, which did not result in "severe" muscle soreness and decrement of muscle function, conferred a protective effect against 50 DJs in a similar magnitude to that conferred by 50 DJs. Thus, it is possible to avoid potential severe muscle damage by performing less demanding DJ exercise 2 weeks prior to more demanding DJ exercise. It should be noted that "untrained" subjects were used in the present study, and it seems likely that "trained" individuals who have been performing resistance training, including some types of plyometric exercises of the lower limbs, experience less damage even after a large number of DJs. It is also important to note that DJ training is generally performed after sufficient strength, speed, and balance trainings (16). However, it is still important for trained individuals and coaches to consider how to introduce plyometrics in the beginning of training season to avoid potential muscle damage, which may affect subsequent training and athletic performance. It is recommended to start from a low number of DJs.

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