Original Article

Effects of a 4-Day Low-intensity Run After Downhill Running on Recovery of Muscle Damage and Running Economy

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This study examined whether a short period of either low-intensity running (LIR) exercise or passive rest following downhill running (DHR) would enhance the recovery of muscle damage and running economy (RE). Twenty-four active males participated in the study, and were randomly assigned into LIR ($n = 12$) and control (CON; $n = 12$) groups. Both groups performed one bout of DHR for 30 minutes on a treadmill with an incline of –26% and at the intensity of 70% of peak oxygen consumption ($\dot{V}O_{2peak}$). The LIR group performed a 30-minute bout of running at a 0% incline and an intensity of 35% of $\dot{V}O_{2peak}$, 30 minutes after the DHR. The 30-minute bout of LIR was repeated each day for 4 days by the LIR group, while the CON group passively rested during the same time period. RE was measured by rate of $\dot{V}O_2$, minute ventilation, respiratory exchange ratio, heart rate, rating of perceived exertion, and stride frequency during a 5-minute bout of level running at 85% of $\dot{V}O_{2peak}$ performed before DHR, and at 2, 5 and 7 days thereafter. Blood lactate concentration was measured before and at 3 minutes after a 5-minute bout of level running (performed before DHR, and at 2, 5 and 7 days thereafter). Maximal isometric voluntary strength of the knee extensor, vertical jump, the level of muscle soreness, plasma creatine kinase activity, and myoglobin concentration were assessed before, immediately after, and every day for 7 days after DHR. All criterion measures were significantly changed ($p < 0.05$) following the DHR for both groups. In addition, the recovery of all criterion measures for the LIR group after DHR was not significantly different ($p > 0.05$) from that of the CON group. These results suggest that a 30-minute bout of LIR every day for 4 days following DHR did not improve the recovery of muscle damage or alter RE.

Keywords: aerobic capacity, eccentric exercise, isometric strength, muscle soreness

Introduction

It is well documented that eccentric exercise can result in muscle damage, the symptoms of which include prolonged loss of muscle function (i.e. strength, vertical jump [VJ], and range of motion), the development of delayed onset muscle soreness (DOMS), elevated muscle proteins in circulation (i.e. creatine kinase [CK] activity),

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limb swelling, and a reduced running economy (RE). "RE" refers to the mechanical efficiency of running and can be determined by the steady-state oxygen consumption ($\dot{V}O_2$) during submaximal running at one fixed velocity on a treadmill in the days after a session of downhill running (DHR) (Chen et al. 2007; Saunders et al. 2004; Braun & Dutto 2003; Kyröläinen et al. 2000). A reduced RE can be manifested by a significant increase in $\dot{V}O_2$ and respiratory exchange ratio (RER) (Chen et al. 2007; Braun & Dutto 2003; Kyröläinen et al. 2000). These changes may last 7 days or more after a single bout of DHR and are related to muscle damage (Byrne et al. 2004; Cheung et al. 2003; Connolly et al. 2003). However, the underlying mechanisms of exercise-induced muscle damage (EIMD) are not fully understood, despite several previous studies suggesting that EIMD may be associated with sarcomere disruption, impaired excitation–contraction coupling, preferential fiber type-II damage, and impaired muscle metabolism (Byrne et al. 2004; Connolly et al. 2003; Proske & Morgan 2001).

Physical activity is one of the many strategies that have been suggested to aid in recovery from EIMD (Cheung et al. 2003; Cleak & Eston 1992; Armstrong 1984; Hough 1902). Several previous studies have demonstrated that exercise can improve recovery from the damage brought on by eccentric exercise of the elbow flexors or knee extensors (Chen et al. 2005; Sayers et al. 2000; Sorichter et al. 1995; Hasson et al. 1989). Sayers et al. (2000) and Chen et al. (2005) found that 4 days of light exercise of the elbow flexors can enhance recovery of muscle strength and muscle soreness from EIMD. Hasson et al. (1989) showed that high-speed voluntary contraction of the quadriceps was effective in alleviating DOMS and facilitating recovery of muscle function after 120 voluntary maximum knee extensions at 5.23 rad s^{-1} (300 deg s^{-1}). Saxton and Donnelly (1995) observed that concentric exercise had effects on serum CK activity and muscle strength. However, these previous studies targeted only a local muscle group—such as elbow flexors or knee extensors—and it is largely unknown whether these findings can be extended to low-intensity running (LIR) exercise in the early days after EIMD.

It has been shown that an intensity of about 35% is the most efficient in aiding recovery from repeated exercise bouts, all-out and competition events (Dodd et al. 1984; Hermansen & Vaage 1977; Belcastro & Bonen 1975), and athletes generally perform a running exercise at submaximal intensity or a reduced exercise intensity to enhance recovery from EIMD (Cheung et al. 2003; Hough 1902). It has been reported that local blood flow increases during and after exercise (Sergueef et al. 2004; Robergs et al. 1997), and it may be that the increased blood flow to a damaged area may help to remove cellular debris, increase nutrient delivery, and enhance tissue repair (Sayers et al. 2000; Robergs et al. 1997; Mohr et al. 1987). It seems that low-intensity exercise may be beneficial for the recovery of both muscle damage and RE from EIMD. Therefore, the purpose of this study was to test the hypothesis that 4 days of LIR following DHR would improve the recovery of muscle damage and RE.

Methods

Subjects and groups

Twenty-four college-age, active and healthy male students (22.4 ± 0.9 years old, 173.3 ± 6.4 cm tall, 66.2 ± 10.2 kg in weight, 11.0 ± 3.1% body fat) participated in the study (which had previously been approved by the local Human Subjects Review Committee) and gave a written informed consent document according to the Declaration of Helsinki. The subjects were randomly assigned into LIR ($n = 12$) and control (CON, $n = 12$) groups by matching the pre-DHR peak aerobic capacity ($\dot{V}O_{2peak}$), using a graded treadmill test (GXT), between the groups. No significant differences ($p > 0.05$) in age, height, body mass or body fat were evident between the groups. No subjects had suffered from any known cardiovascular abnormality, blood disorder, skeletal muscle disease or injury to the legs at any time during the year preceding the study. Subjects were asked to refrain from any physical activity to which they were not accustomed during the measurement period, and were prohibited from doing physical activity for a minimum of 48 hours preceding each testing session. Subjects were also told to refrain from the use of anti-inflammatory agents during the study.

$\dot{V}O_{2peak}$

Preliminary measures included determination of body composition using an Inbody 3.0 Body Composition

Analyzer (Biospace Co. Ltd., South Korea: www.biospace.co.kr) and assessment of $\dot{V}O_{2peak}$ using a GXT. During this test, gas exchange was measured continuously using an automated gas analysis system (Vmax29c, SensorMedics Corp., Yorba Linda, CA, USA). After a warm-up period, the initial treadmill velocity for each subject was set at 3.0 mile hr^{-1} at a 0% grade. Treadmill velocity was increased by 1.0 mile hr^{-1} every 2 minutes until volitional exhaustion. The criteria used to determine $\dot{V}O_{2peak}$ included a RER in excess of 1.1, a heart rate (HR) within 15 beats of the age-predicted maximum, and a leveling off in $\dot{V}O_2$ despite an increase in work (Chen et al. 2007). All subjects satisfied at least two of the three criteria (Chen et al. 2007).

DHR protocol

The DHR protocol was adopted and modified from a previous study by Chen et al. (2007), and the DHR (target duration: 30 minutes) was completed between 48 and 96 hours after RE was first measured. The treadmill was set at a –26% (–15 deg) gradient with a target intensity of 70% of $\dot{V}O_{2peak}$ as determined by the GXT. Prior to beginning this run, each subject completed 5 minutes of self-paced warm-up on a treadmill set at a 0% gradient. A –26% gradient was used for DHR for the following reasons: (a) previous studies (Chen et al. 2007; Braun & Dutto 2003; Eston et al. 2000; Byrnes et al. 1985) that used a lower (–10%) gradient found that a single bout of DHR induced only a mild magnitude of muscle damage; (b) our pilot study found that a –26% gradient with a target intensity of 70% $\dot{V}O_{2peak}$ could induce a greater extent of muscle damage than a –15% gradient.

Thirty minutes of daily running

No subjects performed a warm-up exercise prior to the 5-minute bout of level running at 85% of pre-determined $\dot{V}O_{2peak}$. The LIR group performed a 30-minute bout of running at a 0% incline and an intensity of 35% $\dot{V}O_{2peak}$ 30 minutes after DHR. The 30 minutes of LIR was repeated each day for 4 days by the LIR group, while the CON group rested passively during the same period. The decision to use an intensity of 35% was based on previous studies, which show that this is the most efficient intensity for light exercise done to improve recovery from high-intensity exercise, all-out and competition events (Dodd et al. 1984; Hermansen & Vaage 1977; Belcastro & Bonen 1975). It should be noted that we did not monitor the subjects' daily activities during the experiment. However, we did remind subjects to keep their daily activity as close to "normal" as possible during the experimental period.

Criterion measures

Dependent variables included maximal voluntary isometric strength of the knee extensor (MVC), VJ, perceived muscle soreness (SOR), plasma CK activity, and myoglobin (Mb) concentration, $\dot{V}O_2$, minute ventilation ($\dot{V}_E$), RER, rating of perceived exertion (RPE), lactate, HR, and stride frequency (SF). RE ($\dot{V}O_2$, $\dot{V}_E$, RER, RPE, lactate, HR, SF) was measured at 85% of $\dot{V}O_{2peak}$ before, and at 2, 5 and 7 days after a 30-minute bout of DHR (–26%, –15 deg) at 70% $\dot{V}O_{2peak}$. MVC, VJ, SOR, plasma CK and Mb were assessed before, immediately after, and at 24-hour intervals for 7 days after exercise.

MVC

MVC was assessed at a knee angle of 70 deg on a modified leg curl machine using a force transducer (Model DFG51, Omega Systems Inc., Stamford, CT, USA), which was connected to a digital recorder (MP150, Biopac Systems Inc., Santa Barbara, CA, USA; Chen et al. 2007). Three 3-second repetitions were measured with 1 minute of rest between each contraction. Peak values were recorded, and the mean of the three trials was used as the criterion score.

VJ height measurement

The subjects started from an erect standing position with knees fully extended (knee = 180 deg). Upon the verbal command "Go", they made a downward countermovement to the same starting position as the squat jump (knee = 90 deg) and then jumped vertically for maximum height in one continuous movement (Byrne & Eston 2002). Three jump trials for each time point were used, with 1 minute of rest between each jump (Byrne & Eston 2002). Peak values were recorded, and the mean of the three trials was used as the criterion score.

SOR

SOR data were assessed using a visual analog scale of a 100-mm continuous line, of which one end (0 mm) represented "not sore at all", while the other end (100 mm)

represented "very, very sore" (Chen et al. 2005; Chen 2003). Subjects were asked to record their soreness level on the line during step-downs from a 40-cm bench, and when descending stairs (Braun & Dutto 2003).

RE

Recent studies have found that an RE running test conducted at an intensity of 68% did not produce significant reductions in RE parameters in the days after EIMD (Paschalis et al. 2005; Hamill et al. 1991). In other words, using an intensity of 68% or less may be too low to detect a significant reduction in RE in the days after exercise. Paschalis et al. (2005) and Hamill et al. (1991) suggested that future studies should use a higher intensity as an RE test. Chen et al. (2007) and Braun & Dutto (2003) reported that an 85% intensity could detect a significant reduction in RE in the days after DHR. Thus, we decided to adopt an 85% intensity as an RE test protocol in the study.

The first RE test was performed a minimum of 48 hours after the GXT, but not more than 1 week later. Prior to measuring RE, subjects were oriented to the treadmill and to the gas collection system. All testing was performed between 07:00 and 12:00, and the testing time for each subject was held consistent. After subjects arrived at the laboratory, a resting fingertip blood sample was collected for lactate measurement (Lactate Pro™, Tester Meter, Arkray Inc., Kyoto, Japan). The subjects were fitted with an HR transmitter, and then instructed to complete a 5-minute bout of level running at 85% $\dot{V}O_{2peak}$ (Chen et al. 2007; Braun & Dutto 2003). Fingertip samples were collected at 3 minutes after the 5-minute bout of level running, and at 2, 5 and 7 days after DHR for blood lactate analysis. All blood samples were collected with the subjects in a standing position, and were analyzed immediately after collection (Chen et al. 2007; Braun & Dutto 2003). During the running, expired gas was continually collected using an automated gas analysis system (Vmax29c, SensorMedics Corp.). Average $\dot{V}O_2$, $\dot{V}_E$, and RER values for the last 45 seconds of level running at 85% intensity were obtained. HR was measured by an HR monitor (Polar S610, Kempele, Finland) during the level running, and the mean value of the last 45 seconds at 85% intensity was used for further analysis (Chen et al. 2007). RPE was obtained during the last 20 seconds of 85%-intensity running using the Borg's scale (RPE; Chen et al. 2007; Borg 1970), and SF was determined by visual count during the 4th minute of each run.

It should be noted that data during the last 45 seconds were analyzed to determine RE for the following reasons: (a) $\dot{V}O_2$, $\dot{V}_E$ and RER levels are more stable during the last 45 seconds than during the first few minutes; (b) this was the procedure generally followed in previous studies (Chen et al. 2007; Braun & Dutto 2003).

Blood analysis

All subjects in the study visited the laboratory in the morning for venipuncture. Approximately 10 mL of blood was drawn from the antecubital vein, and then centrifuged for 10 minutes to obtain plasma samples. After separation, all samples were stored at −20°C until analysis for CK activity and Mb concentration. Plasma CK activity was determined spectrophotometrically by a Genstar chemistry analyzer (Electro-Nucleonics, Fairfield, NJ, USA) using test kits (Sigma Diagnostics, St. Louis, MO, USA). Plasma Mb concentration was measured by a biochemical analyzer (Model ADVIA-Centaur, Bayer Co. Ltd., Germany) using test kits (Denka-Seiken Co. Ltd., Japan). Samples were analyzed in duplicate, and the mean of both measures was used for subsequent statistical analysis. The normal reference ranges in men for CK and Mb were 38–174 IU L^{-1} and 16–76 μg L^{-1}.

Reliability

Reliability of the MVC, VJ, SOR and RE ($\dot{V}O_2$) measures was determined by the intraclass correlation coefficient between the values taken on 2 different days, between 1 and 5 days before DHR. RE was assessed in all subjects at a treadmill speed that elicited an intensity of 85% $\dot{V}O_{2peak}$ on 2 different days before DHR. The correlation of $\dot{V}O_2$ between these 2 different days was $r = 0.96$ for 85% of the pre-determined $\dot{V}O_{2peak}$. The r values for reliability in the criterion measures were $r = 0.98$ for MVC; $r = 0.96$ for VJ; and $r = 1.00$ for SOR ($p < 0.01$).

Statistical analysis

Dependent variables were entered into a two-way mixed-design analysis of variance (ANOVA). When ANOVA found a significant interaction (group × time) effect, Tukey's *post hoc* test was conducted to specify the time

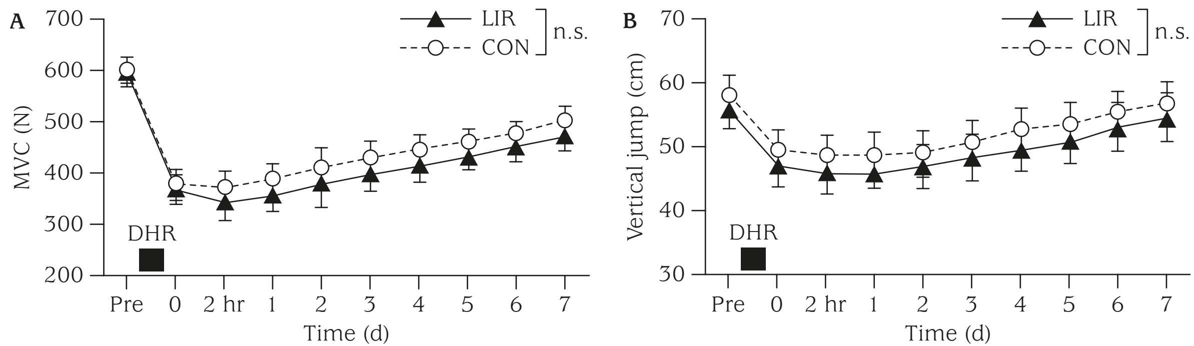

Fig. 1 Changes in (A) maximal leg extensor isometric force (MVC) and (B) vertical jump (VJ) (mean ± standard deviation) before and for 7 days following the downhill run (DHR) for the LIR and CON groups. "Pre" indicates the baseline period and "0" indicates the time period immediately post-DHR. MVC measurements were taken immediately after DHR to 7 days after DHR. No significant differences ($p > 0.05$) between the groups were found.

points where significant differences were evident. Values of $p < 0.05$ were considered to be statistically significant.

Results

LIR on muscle damage

All criterion measures (MVC, VJ, SOR, CK, Mb) saw significant changes ($p < 0.05$) following DHR, but without significant difference ($p > 0.05$) between the groups (Figures 1 and 2). As shown in Figure 1A, MVC decreased significantly ($p < 0.05$) immediately after DHR for both LIR and CON groups, and further decreased at 2 hours after DHR for both groups. Following this, both the LIR and CON groups started to gradually regain MVC. It should be noted that the recovery of MVC following DHR in the LIR group was not significantly faster ($p > 0.05$) than it was for the CON group (Figure 1A). This was also the case for VJ (Figure 1B), soreness (Figure 2A), CK (Figure 2B), and Mb (Figure 2C). For instance, CK and Mb both saw significant increases ($p < 0.05$) between 2 hours and 1 day following DHR, and peaked at between 5 and 6 days after DHR for both groups (Figures 2B & C). In the same way, the recovery of CK (Figure 2B) and Mb (Figure 2C) following 4 days of LIR after DHR in the LIR group was not significantly faster ($p > 0.05$) than that of the CON group.

LIR on RE

All RE parameters ($\dot{V}O_2$, $\dot{V}_E$, RER, HR, lactate, RPE, SF) showed significant changes ($p < 0.05$) following DHR for both groups, without a significant difference ($p > 0.05$) between the groups (Figures 3 & 4). It should be noted that SF data are not shown in the text. Between 2 and 7 days after DHR, $\dot{V}O_2$, expressed as milliliters per kilogram per minute (mL kg min^{-1}), was significantly elevated ($p < 0.05$) from pre-DHR levels for both the LIR and CON groups (Figure 3A). The case was the same for the rest of the RE parameters (Figures 3 & 4). $\dot{V}_E$, RER, HR, lactate, RPE and SF were significantly elevated ($p < 0.05$) at 2 days after DHR, and failed to return to baseline at 7 days after DHR for both groups (Figures 3 & 4). Although there were slightly higher changes in all RE parameters for the LIR group than for the CON group, no significant differences ($p > 0.05$) in any of the parameters were observed between groups (Figures 3 & 4).

Discussion

The purpose of this study was to test the hypothesis that running at 35% intensity for 4 consecutive days following DHR would enhance the recovery of muscle damage and RE. It was discovered that immediately after DHR, MVC significantly decreased to 30% for both groups (Figure 1A). Moreover, DHR also induced similar levels of muscle soreness, CK and Mb for both groups (Figures 1 & 2), and the case was the same for RE measures ($\dot{V}O_2$, $\dot{V}_E$, RER, lactate, HR, RPE, SF) for both groups (Figures 3 & 4). Since DHR induced a similar degree of muscle damage and a similar decrease in RE for both groups (Figures 1–4), it seems reasonable to assume that any subsequent differences can be attributed to the effects of

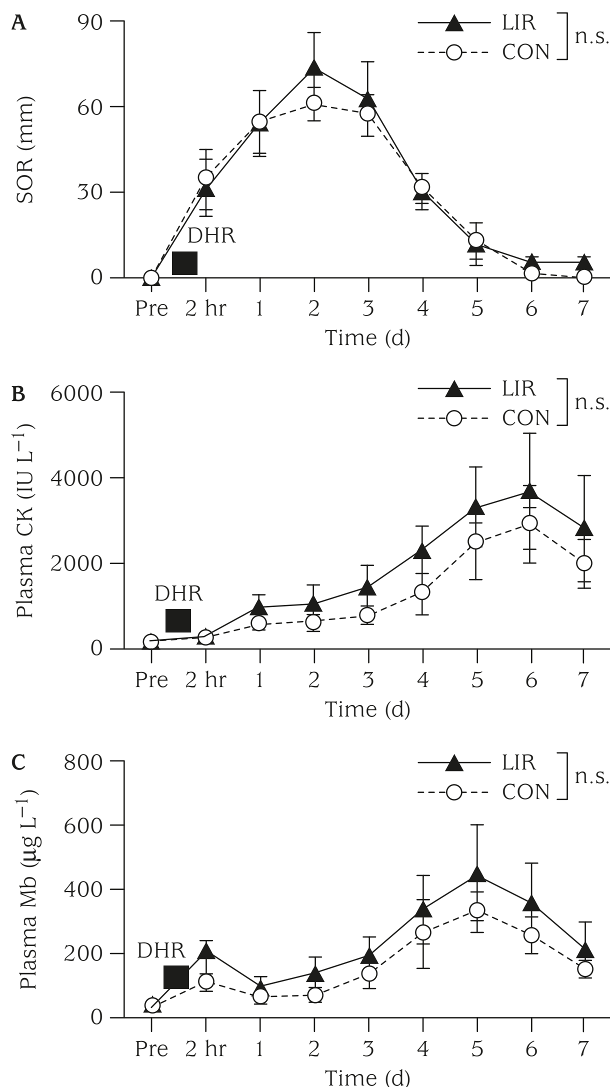

Fig. 2 Changes in (A) muscle soreness (SOR), (B) plasma creatine kinase activity (CK) and (C) myoglobin concentration (Mb) (mean ± standard deviation) over 7 days after DHR for the LIR and CON groups. "Pre" indicates the baseline period. Plasma CK and Mb were assessed before, at 2 hours, and 1–7 days after DHR. No significant differences ($p > 0.05$) between the groups were found.

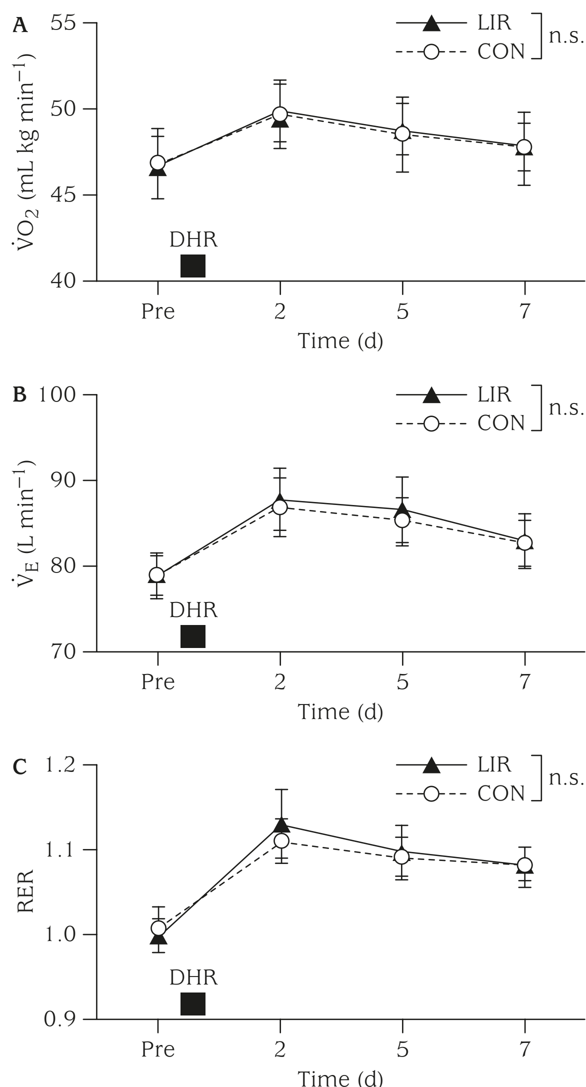

Fig. 3 Changes in (A) oxygen consumption ($\dot{V}O_2$) (mL kg min^{-1}), (B) $\dot{V}_E$ (L min^{-1}), and (C) RER at 85% of $\dot{V}O_{2peak}$ (mean ± standard deviation) before (Pre) and at 2, 5 and 7 days after DHR for the LIR and CON groups. "Pre" indicates the baseline period. No significant differences ($p > 0.05$) between the groups were found.

LIR. However, the results of the present study showed that performing a bout of LIR for 4 consecutive days following DHR produced neither a temporary nor a long-lasting improvement in the recovery of muscle damage indicators (i.e. MVC, VJ, SOR, CK, Mb) or RE ($\dot{V}O_2$, $\dot{V}_E$, RER, HR, RPE, lactate, SF) (Figures 1–4). We do not rule out the possibility that the indirect indicators of muscle damage and RE used in this study could have partially affected the final results of this study.

Physical activity has been reported to enhance the recovery of muscle strength and relief from muscle soreness (Chen et al. 2005; Sayers et al. 2000; Sorichter et al. 1995; Saxton & Donnelly 1995; Hasson et al. 1989). It would appear that the increases in blood flow caused by light exercise played a role in the recovery of muscle strength (Chen et al. 2005; Sayers et al. 2000; Saxton & Donnelly 1995). Previous studies showed that blood flow in muscle tissue increased up to five-fold during

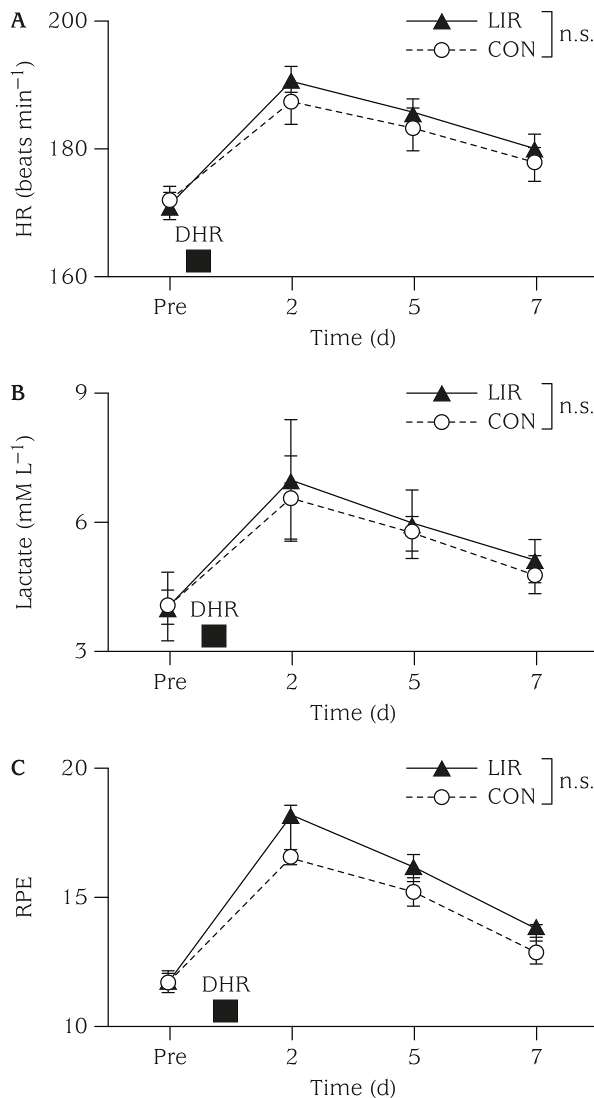

Fig. 4 Changes in (A) HR (beats min^{-1}), (B) lactate (mM L^{-1}), and (C) RPE at 85% of $\dot{V}O_{2peak}$ (mean ± standard deviation) before (Pre) and at 2, 5 and 7 days after DHR for the LIR and CON groups. "Pre" indicates the baseline period. No significant differences ($p > 0.05$) between the groups were found.

concentric exercise (Sergueef et al. 2004; Robergs et al. 1997; Mohr et al. 1987). Blood flow is an important factor in reducing pain, facilitating the healing of damaged muscle, reducing swelling (Mohr et al. 1987), and enhancing the efficiency of muscle contraction (Clemente et al. 1991). However, this contention may not explain our results. The results of this study showed that recovery of MVC, VJ, SOR, CK and Mb for the LIR group was no faster than it was for the CON group (Figures 1 & 2). These results are inconsistent with the findings of previous studies (Chen et al. 2005; Sayers et al. 2000; Saxton & Donnelly 1995; Sorichter et al. 1995; Hasson et al. 1989), which showed that exercise could enhance recovery from EIMD. The exercise protocol used in the present study was different from those used in previous studies (Chen et al. 2005; Sayers et al. 2000; Saxton & Donnelly 1995; Sorichter et al. 1995; Hasson et al. 1989). The subjects in the LIR group of the present study performed a daily running exercise, while those in previous studies performed daily exercise of a local muscle group, such as the elbow flexors or knee extensors. Chen et al. (2005) and Sayers et al. (2000) reported that 4 days of light exercise of the elbow flexors can enhance recovery of muscle strength and muscle soreness from EIMD. Hasson et al. (1989) reported that a high-speed voluntary contraction of the quadriceps was effective in alleviating DOMS and facilitating recovery of muscle function after 120 voluntary maximum knee extensions at 5.23 rad s^{-1} (300 deg s^{-1}). Saxton & Donnelly (1995) showed that concentric exercise had effects on serum CK activity and muscle strength.

RE has been recognized as one of the most important physiologic variables associated with running performance (Chen et al. 2007; Saunders et al. 2004; Braun & Dutto 2003). Several studies have established that RE parameters could be impaired following DHR (Chen et al. 2007; Braun & Dutto 2003); however, research studies examining the effects of short-term light exercise following EIMD to muscles involved in lower body locomotion are limited. Braun & Dutto (2003) showed that $\dot{V}O_2$ and lactate were elevated and stride mechanics were reduced at three relative intensities (65%, 75% and 85% of $\dot{V}O_{2peak}$) in the days after DHR compared to pre-DHR levels. This suggests that muscle damage led to changes in stride mechanics, contributing to the change in RE during DOMS. As shown in Figure 3A, the changes in $\dot{V}O_2$ following LIR after DHR for the LIR group were not significantly different compared to those of the CON group. This was the case for $\dot{V}_E$ (Figure 3B), RER (Figure 3C), HR (Figure 4A), lactate (Figure 4B), RPE (Figure 4C), and SF (not shown in the text). These results suggest that LIR following DHR had neither a positive nor a negative effect on the recovery of RE.

Possible explanations for why LIR in the early days following DHR did not enhance recovery of RE (Figures 3 & 4) are unclear but may be related to the DHR exercise

protocol that was used in this study. Armstrong (1986) and Clarkson & Sayers (1999) reported that EIMD resulted from metabolic and/or mechanical stress. It should be noted that DHR-induced muscle damage is related mainly to a metabolic overload, while muscle damage induced by the action of local eccentric muscles (i.e. elbow flexors or knee extensors) is primarily associated with a mechanical strain (Clarkson & Sayers 1999; Armstrong 1986). In a recent review paper, Connolly et al. (2003) postulated that exercise is one efficient intervention for enhanced recovery from EIMD that is related to mechanical stress. These points seem to explain why the findings of previous studies (Chen et al. 2005; Sayers et al. 2000; Saxton & Donnelly 1995; Sorichter et al. 1995; Hasson et al. 1989) showed that daily exercise could significantly improve recovery from a bout of eccentric exercise of the elbow flexors or knee extensors, and why our findings showed that exercise did not facilitate recovery from DHR (Figures 3 & 4).

It has been shown that muscle glycogen resynthesis and glucose transporter GLUT4 protein in human skeletal muscles were impaired after eccentric exercise due to muscle damage (Asp et al. 1995; Costill et al. 1990). These factors, in turn, may lead to a reduction in both muscle function and RE following DHR (Figures 1–4). Several studies postulated that mechanical changes in running associated with DOMS may increase the risk of further musculoskeletal injury if exercise is sustained while the symptoms persist (Braun & Dutto 2003; Cheung et al. 2003). Therefore, it seems likely that engaging in light exercise that loads the muscles in the same fashion as running while recovering from DHR-induced DOMS may result in stress on damaged muscles. Such exercise, therefore, cannot significantly improve recovery of muscle damage or RE parameters. Further studies are needed to examine whether a non-weight-bearing activity (e.g. cycle ergometry or swimming) after EIMD would be more beneficial compared to a weight-bearing exercise (e.g. running).

In conclusion, LIR in the early stage after DHR neither improved the recovery of muscle damage and RE parameters nor slowed recovery from EIMD. Future studies are needed to examine whether a non-weight-bearing activity (e.g. cycle ergometry or swimming) after EIMD would be more beneficial compared to a weight-bearing exercise.

Acknowledgments

The authors would like to thank the National Science Council of Taiwan for their financial support of this study under Contract No. NSC 94-2815-C-415-028-H.

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