European Journal of Sport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tejs20

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To cite this article: Trevor C. Chen, Yuh-Chuan Huang, Tai-Ying Chou, Sheng-Tsung Hsu, Mei-Yen Chen & Kazunori Nosaka (2023): Effects of far-infrared radiation lamp therapy on recovery from muscle damage induced by eccentric exercise, European Journal of Sport Science, DOI: 10.1080/17461391.2023.2185163

To link to this article: https://doi.org/10.1080/17461391.2023.2185163

Published online: 15 Mar 2023.

EUROPEAN JOURNAL OF SPORT SCIENCE
https://doi.org/10.1080/17461391.2023.2185163

ORIGINAL INVESTIGATION

Effects of far-infrared radiation lamp therapy on recovery from muscle damage induced by eccentric exercise

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ABSTRACT

The present study investigated the effects of a far-infrared radiation (FIR) lamp therapy on changes in muscle damage and proprioception markers after maximal eccentric exercise of the elbow flexors (EF: Study 1) and the knee flexors (KF: Study 2) in comparison to a sham treatment condition. In each study, 24 healthy sedentary women were assigned to a FIR or a sham treatment group ($n = 12$/group). They performed 72 maximal EF eccentric contractions (Study 1) or 100 maximal KF eccentric contractions (Study 2) with their non-dominant limbs. They received a 30-min FIR (wavelength: 8–14 μm) or sham treatment at 1, 25, 49, 73 and 97 h post-exercise to the exercised muscles. Maximum voluntary isometric contraction (MVC) torque, muscle soreness, plasma creatine kinase activity, and proprioception assessed by position sense, joint reaction angle, and force match were measured before, and 0.5, 24, 48, 72, 96 and 120 h post-exercise. The outcome measures showed significant changes ($P < 0.05$) at 0.5-hour post-exercise (before treatment) similarly ($P > 0.05$) between the conditions in both studies. However, changes in all measures at 24–120 h post-exercise were smaller ($P < 0.05$) for the FIR than sham condition in both studies. For example, MVC torque returned to the baseline by 72 h post-exercise for the FIR condition in both studies, but was still 19 ± 6% (Study 1) or 17 ± 12% (Study 2) lower than the baseline at 120 h post-exercise for the sham condition. These results suggested that the FIR lamp therapy was effective for accelerating recovery from muscle damage.

Highlights

- FIR lamp therapy was effective for recovering muscle strength and proprioception 1–3 days faster to the baseline.
- FIR lamp therapy was effective for attenuating muscle soreness by 55–60%, and reducing peak plasma CK activity by 45–89%.
- The effects of the FIR lamp therapy appear to be greater than other therapeutic interventions for eccentric exercise-induced muscle damage that have been investigated previously.

KEYWORDS
Lengthening muscle contraction; delayed onset muscle soreness; proprioception

Introduction

Unaccustomed eccentric exercise induces muscle damage that is represented by a prolonged loss of muscle function, delayed onset muscle soreness (DOMS), and increases in plasma creatine kinase (CK) activity (Chen, Huang et al., 2020). It also impairs proprioception such as position sense (PS) and force match (FM), probably due to its effects on muscle spindles and tendon organs (Brockett et al., 1997; Paschalis et al., 2010). These symptoms of muscle damage could last for several days post-exercise, although the time taken to a full recovery is depending on the severity of the muscle damage (Hyldahl et al., 2017). It is important to minimise muscle damage and eliminate the symptoms as early as possible, since they have negative effects on daily activities, the ability to perform subsequent exercise bouts, adherence to regular exercise, and athletic performance (Byrne et al., 2004).

To facilitate recovery from eccentric exercise-induced muscle damage (EIMD), a variety of therapeutic treatments including medications such as nonsteroidal anti-inflammatory drugs, nutritional supplements (Howatson & van Someren, 2008), and physical therapies with heat, cold, electricity, ultrasound, vibration, or radiation (Abaïdia et al., 2017; Fritsch et al., 2016; Kim et al., 2020; Lau & Nosaka, 2011) are often used. Among

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physical therapies, a local heat therapy (Kim et al., 2020), cold-water immersion (Abaïdia et al., 2017), light-emitting diode therapy (Chang et al., 2021), low-level laser therapy (Fritsch et al., 2016), near-infrared light therapy (Larkin-Kaiser et al., 2015), and vibration treatment (Lau & Nosaka, 2011) have been shown to have some effects on DOMS and other muscle damage markers. However, the magnitude of the effects found in these studies do not appear to be large in terms of the physiological benefits such that peak DOMS was attenuated by less than 10%. Other studies did not find significant effects of similar interventions and other modalities (e.g. electrical stimulation) on DOMS or other muscle damage markers (Allen et al., 1999; Hasson et al., 1992; Stay et al., 1998). Therefore, a more effective intervention to facilitate muscle damage recovery, if any, is useful.

Far-infrared radiation (FIR) therapy is in the category of phototherapy in which a wavelength of 3–1000 µm is used, and the best wavelength for human body is documented to be 8–14 µm to increase cell growth and development (Vatansever & Hamblin, 2012). FIR therapy has been reported to enhance skin wound healing (Toyokawa et al., 2003), increase blood nitric oxide concentration (Yu et al., 2006), provide anti-inflammatory effects (Leung et al., 2012), relieve pain and muscle stiffness (Lai et al., 2014), and increase peripheral microcirculation (Leung et al., 2011). Comparing to other thermal modalities, a FIR can penetrate to tissue deeper (approximately 4 cm from the skin), and is safe, simple, noninvasive, and painless (Leung, 2015; Vatansever & Hamblin, 2012). Thus, a FIR therapy may be effective for facilitating recovery from EIMD. However, to the best of our knowledge, only two studies (Hsieh et al., 2022; Nunes et al., 2019) have examined the effect of FIR therapy on EIMD.

In the study by Nunes et al. (2019), the participants (physically active men) wore a FIR emitting ceramic material pants for 2 h at immediately, 24, 48 and 72 h after 3 sets of 30 maximal isokinetic (60°/s) eccentric contractions (MaxEC) of the unilateral knee extensors (KE). The results showed no significant difference between the FIR and sham interventions for changes in muscle function, DOMS, plasma CK and lactate dehydrogenase activities. However, the magnitude of muscle damage induced by the exercise appeared to be minor as indicated by a small increase in plasma CK activity (peak: ~300 IU/L). Paulsen et al. (2012) stated that post-exercise peak CK activity represents the magnitude of muscle damage such that <1000 IU/L indicates mild damage, and >10,000 IU/L indicates severe muscle damage. In order to investigate the treatment effects on EIMD, its magnitude of muscle damage is better to be more than mild. It is also possible that wearing FIR pants for 2 h was not the best way to produce significant effects of FIR on outcome measures. Thus, the effects of a FIR therapy on muscle damage could be better investigated using a different muscle damage model that could induce larger changes in indirect muscle damage markers such as muscle function, DOMS, and plasma CK activity, and using a FIR lamp therapy that could provide stronger irradiation intensity to the target muscles. Hsieh et al. (2022) recently reported that a 30-minute daily FIR lamp therapy targeting on KE and knee flexors (KF) reduced muscle damage and enhanced recovery from performing six consecutive soccer simulated matches by elite female soccer players when compared to a sham FIR therapy. However, the findings of the study should be confirmed by a laboratory study in which the magnitude of muscle damage is better controlled.

Therefore, the present study tested the hypothesis that a daily FIR lamp therapy after MaxEC of the elbow flexors (EF) and the KF would enhance the recovery of muscle function and proprioception, reduce DOMS, and attenuate increases in plasma CK activity, when compared with a sham treatment condition. The two different muscle groups were investigated in the present study in the assumption that the effects of the FIR therapy might be different between arm and leg muscles, because their muscle volumes are different, and it was possible that the magnitude of muscle damage would be different between the EF and KF (Chen et al., 2011). Moreover, hamstring muscle strains are the most frequent sporting injuries, particularly in sports that involve sprinting and kicking a ball (Kujala et al., 1997). Thus, the EIMD of the KF could be used as a model to predict the efficacy of a FIR lamp therapy on hamstring strains.

Materials and methods

Participants and study design

The effects of a FIR therapy on muscle damage induced by MaxEC of the EF (Study 1) and the KF (Study 2) were investigated using different participants (12 participants for each study). In both studies, changes in indirect muscle damage markers following a bout of MaxEC were compared between the FIR and sham treatment groups. The present study recruited female participants only to reduce variability in responses to eccentric exercises, since sex differences could exist (Davies et al., 2018; Sayers & Clarkson, 2001), and we had better access to sedentary female than male participants.

The sample size estimation of each study was based on our pilot study that compared the FIR and sham conditions using 6 participants, respectively. Based on the result showing that the extent of decrease in maximal isometric contraction (MVC) torque of the KF was 23.0 ± 7.3% for a FIR group and 33.3 ± 10.3% for a sham group, the effect size (d) was 1.2 (large). Using the effect size, with **α** level of 0.05 and **β** level of 0.2, it was shown that a minimum of 10 participants per group were necessary (G*Power 3.1.9.2, Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, Germany). Considering possible dropouts and estimation error, 24 young sedentary healthy women were recruited for each study. They were placed into a FIR or a sham treatment group ($n = 12$/group) by stratifying their pre-exercise average MVC torque to be similar between the groups based on the same method using the studies of previous studies (Chen et al., 2011; Chen, Huang et al., 2020).

Their physical characteristics were age: 22.0 ± 1.5 y, height: 161.9 ± 3.8 cm, body mass: 57.8 ± 5.2 kg, body mass index: 22.0 ± 1.5 kg/m^2 in Study 1, and 20.9 ± 0.8 y, 162.9 ± 5.4 cm, 53.7 ± 6.3 kg, and 20.3 ± 2.7 kg/m^2, respectively in Study 2. The studies were approved by the University Research Ethics Committee where the studies were performed, and each participant gave an informed consent before participation in the study. The participants were asked and reminded to refrain from unaccustomed exercises and/or vigorous physical activities, maintain their normal dietary habits and not to take any anti-inflammatory drugs or nutritional supplements during the experimental period. The study was conducted in conformity with the policy statement regarding the use of human participants by the Declaration of Helsinki.

Familiarisation session

A familiarisation session was held 3 days before the MaxEC, in which the participants experienced the measurements of muscle soreness, PS and joint reaction angle (JRA), MVC torque and FM measures in this order. The investigator demonstrated the exercise, but no MaxEC were performed by the participants.

Eccentric exercises

The protocols to induce muscle damage to the EF (Study 1) and KF (Study 2) were adopted and modified from the previous studies (Franklin et al., 1993; Lauritzen et al., 2009). The use of the larger number of contractions for the KF ($n = 100$) than EF ($n = 72$) was to induce a similar level of muscle damage to both muscles, since it has been reported that the same number of MaxEC ($n = 30$) induced less damage for the KF than the EF (Chen et al., 2011).

In Study 1, the participants performed 12 sets of six MaxEC (30°/s) of the non-dominant EF on an isokinetic dynamometer (Biodex System S4, Biodex Medical Systems, Shirley, NY) from an elbow flexed (90°) to an elbow fully extended position (0°). Each contraction lasted for 3 s and was repeated every 10 s during which the isokinetic dynamometer passively returned the elbow joint to the flexed position at the velocity of 9°/s, with a 2-minute rest between sets. The mean torque of each set was obtained and used for subsequent analysis, and the total work (TW) was also calculated as the sum of the work of 72 MaxEC. In Study 2, the participants performed 10 sets of 10 MaxEC (30°/s) of the KF from 90° knee flexion to a full knee extension using their non-dominant (not used for kicking a ball) legs. The contraction time and the rest between contractions and sets were the same as those of Study 1.

FIR and sham treatments

In the FIR treatment, a commercially available "FIR lamp" (EQ-A718 ITU Far-Infrared Therapy Unit; Chen Yeh Technology Health Co, Ltd., Taichung, Taiwan) was used. The FIR lamp is made of a solid ceramic (size: 139.4 × 139.4 × 9.5 mm) and radiate the light of wavelength: 8–14 µm (emissivity: 0.96; power output: 280 W ± 10%; power density: 1.71 W/cm^2; energy density: 3078 J/cm^2). The participants received a 30-minute FIR lamp therapy to the surface of the EF (Study 1) and KF (Study 2). The cumulative dose per session was 1,006,414 J for the EF and 2,203,694 J for the KF, because two lamps were used for the KF (Figure 1) and the surface of the KF (average: 716 cm^2) was lager than the EF (average: 327 cm^2). The sham treatment was done by the same device without the radiation for 30 min. Each participant sat on a chair with her exercised arm being placed on a table in a relaxed position in Study 1 (Figure 1(A)). In Study 2, two FIR lamps were used to cover a larger muscle (the KF) than the EF, and each participant was in a lay prone position, and her exercised leg was placed on a message table in a relaxed position (Figure 1(B)). In both studies, the FIR lamp was aligned with the belly of the exercised muscle, and the distance between the lamp and surface of the muscle was approximately 20 cm based on the recommendation from the company (Figure 1). The FIR and sham treatments were applied at 1, 25, 49, 73 and 97 h after MaxEC. In order to eliminate potential psychological effects, each participant wore an eye mask and a headphone with music of her choice (Figure 1) to prevent any speculation for the treatment (FIR or sham). The same physical therapist carried out the FIR and sham treatments, and this was the only person who knew

Figure 1. Far-infrared radiation (FIR) therapy set-up for the elbow flexors (A) and knee extensors (B). One FIR lamp was used for the elbow flexors, but two FIR lamps were used for the knee flexors in the treatment for 30 min a session. A photo release form was obtained from the persons in the photos.

the condition of the treatment (FIR, sham) of each participant during the data collection period.

Dependent variables

The dependent variables included MVC torque, muscle soreness assessed by a visual analog scale (VAS), plasma CK activity, PS, JRA and FM for both studies. The measurements except muscle soreness and plasma CK activity were taken immediately before and 0.5 h after exercise and every 24-hour interval for 5 consecutive days after MaxEC. Muscle soreness and plasma CK activity were assessed before and every 24-hour interval for 5 consecutive days post-MaxEC. The test–retest reliability and the coefficient of variation (CV) of these measurements were shown to be high in previous studies (Chen et al., 2011; Chen, Huang et al., 2020).

MVC torque

MVC torque was measured by the same isokinetic dynamometer and in the same position as those described for the MaxEC. MVC torque was measured at the elbow flexion of 90° (Study 1) or the knee flexion of 30° (Study 2). Verbal encouragement was provided during the MVC torque measures. The highest value of the three trials was used for further analysis (Chen, Huang et al., 2020; Chen et al., 2021; Lin et al., 2022).

Muscle soreness

Muscle soreness of the EF (Study 1) or the KF (Study 2) were quantified using a VAS that had a 100-mm continuous line with "'no pain at all'" on one end (0-mm) and "'unbearable pain'" on the other end (100-mm). The participants were asked to rate their perceived soreness rating on the VAS when the elbow joint (Study 1) or the knee joint (Study 2) was passively extended to a full extension position (Chen, Yang et al., 2020; Kang et al., 2022).

Plasma CK activity

Approximately 3-mL of venous blood was drawn from the antecubital vein using a standard venipuncture technique and centrifuged for 10-minute to separate the plasma, and plasma samples were stored at −80°/C for later analyses. Plasma CK activity was assayed via spectrophotometry by an automated clinical chemistry analyser (Model 7080; Hitachi, Co. Ltd., Tokyo, Japan) using a commercially available test kit (Roche Diagnostics, Indianapolis, Indiana; Chen et al., 2019). The normal reference range for plasma CK activity in women were 26–192 IU/L based one the manufacturer's information.

Position sense (PS), joint reaction angle (JRA), and force match (FM)

PS at 30° (PS30), 45° (PS45) and 60° (PS60) of the unilateral elbow flexion (Study 1) and knee flexion (Study 2), JRA at 30° (JRA30), 45° (JRA45) and 60° (JRA60) of the elbow flexion (Study 1) and knee flexion (Study 2), and FM at 30% of pre-exercise MVC torque of the EF (Study 1) and the KF (Study 2) were measured by the isokinetic dynamometer, in the same position as those described for the MaxEC. The details of these three measurements can be found in previous studies (Chen, Huang et al., 2020; Paschalis et al., 2010).

Statistical analyses

The Shapiro–Wilk test was used to verify the normality assumption of the data. The result of this test showed that normality assumption was met for all variables in both studies. Baseline values for all dependent variables before MaxEC were compared between the two groups in each study by an independent t-test. Changes in peak torque and work during MaxEC were compared between the FIR and sham groups in each study by a mixed-design two-way analysis of variable (ANOVA). Changes in the dependent variables after MaxEC were also compared between the FIR and sham groups in each study by a mixed-design two-way ANOVA. When the ANOVA found a significant interaction effect, a Tukey's post-hoc test was performed for the comparison between groups for each time point. Eta-squared values (η^2) were calculated as measures of effect size, and they were considered ∼0.02 as small effect, ∼0.13 as medium effect and >0.26 as large effect (Bakeman, 2005) when necessary. A significant level was set at $P < 0.05$. The data are presented as mean ± standard deviation (SD), unless otherwise stated. All statistical analyses were performed using the Statistical Package for Social Sciences Version 23.0.

Results

Baseline measures and exercise

No significant differences ($P > 0.05$) in any of the baseline dependent variables existed between the FIR and sham groups before MaxEC for both studies (Figures 2 and 3). The average TW during MaxEC of the EF was similar ($P = 0.427$, $\eta^2 = 0.058$) between the FIR (2001 ± 255 J) and sham (1955 ± 246 J) conditions. The TW in the KF exercise was also similar ($P = 0.830$, $\eta^2 = 0.004$) between the FIR (5543 ± 1567 J) and sham (5634 ± 1503 J) conditions. Similar results were also found (EF: $P = 0.176$, $\eta^2 = 0.159$; KF: $P = 0.912$, $\eta^2 = 0.001$) in the average peak torques generated during MaxEC of the EF between the FIR (27.9 ± 3.2 Nm) and sham (26.2 ± 3.2 Nm) conditions and KF between the FIR (43.6 ± 10.6 Nm) and sham (47.7 ± 12.5 Nm) conditions, respectively.

Changes in the dependent variables

In both studies, all dependent variables showed significant (time effect: all $P < 0.05$) changes at 0.5-hour after MaxEC (before treatment) without significant (group effect & interaction effect: all $P > 0.05$) differences between the FIR and sham groups (Figures 2 and 3). However, the variables returned to the baseline faster ($P < 0.001$) for the FIR than the sham group (EF: interaction effect; e.g. MVC: $\eta^2 = 0.740$; PS45: $\eta^2 = 0.793$; JRA45: $\eta^2 = 0.886$; FM: $\eta^2 = 0.878$; KF: interaction effect; e.g. MVC: $\eta^2 = 0.534$; PS45: $\eta^2 = 0.339$; JRA45: $\eta^2 = 0.675$; FM: $\eta^2 = 0.620$), and increases in muscle soreness (interaction effect; EF: $\eta^2 = 0.851$; KF: $\eta^2 = 0.504$) and plasma CK activity (interaction effect; EF: $\eta^2 = 0.865$; KF: $\eta^2 = 0.396$) were smaller for the FIR than sham group (Figures 2 and 3).

Discussion

We hypothesised that the daily FIR lamp therapy after MaxEC would enhance the recovery of muscle damage and proprioception markers, when compared with the sham treatment condition. The results showed that changes in the muscle damage and proprioception markers immediately after MaxEC (before treatment) were similar between the FIR and sham groups in each study, but the markers returned to the baseline faster for the FIR than sham group, and peak DOMS and plasma CK activity were significantly lower for the FIR than sham group (Figures 2 and 3). These results supported the hypothesis and suggested that the FIR therapy was effective for enhancing recovery from muscle damage.

It is important to note that the changes in MVC torque from baseline to 0.5 h after exercise were similar between the FIR and sham treatment groups in Study 1 (Figure 2(A)) and Study 2 (Figure 3(A)), respectively. These acute changes were likely to be induced by a combination of neuromuscular fatigue and muscle damage (Royer et al., 2021), but the similar changes in the measures before the first FIR treatment that was performed at 0.5 h post-exercise, indicate that the MaxEC induced similar neuromuscular fatigue and/or muscle damage before the first treatment in both studies. The changes in the measures in the sham conditions were similar to those reported in the previous studies in which a similar exercise protocol to that of the present study was used without any treatment for the EF (Lauritzen et al., 2009) and KF (Franklin et al., 1993). It appeared that the magnitude of muscle damage was more than "mild" since post-exercise peak CK activity exceeded 1000 IU/L (Paulsen et al., 2012) in both studies for the sham treatment condition. It seems likely that the faster recovery of the variables between 24 and 120 h after MaxEC for the FIR than the sham condition indicates the positive FIR lamp therapy effects. For the FIR condition, MVC torque and proprioception

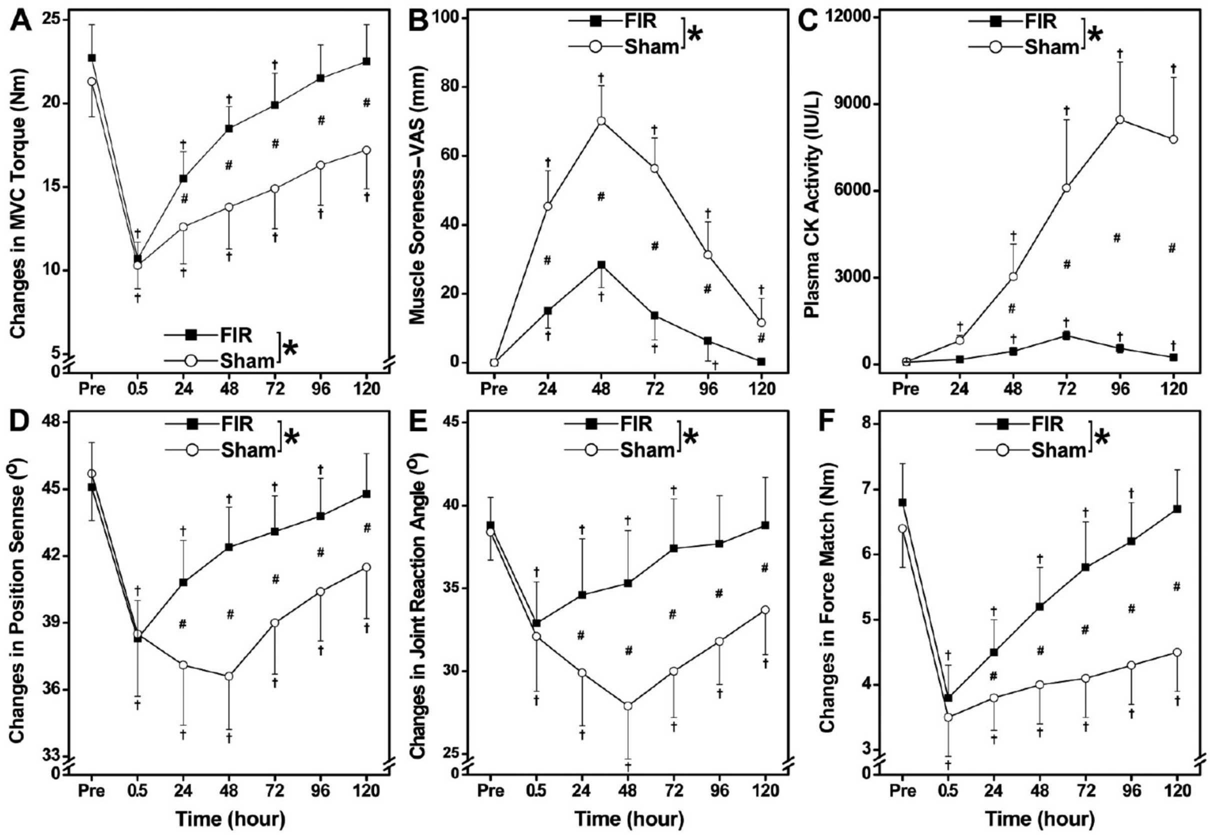

Figure 2. Changes in maximal isometric contraction (MVC) torque (A), muscle soreness (B), plasma creatine kinase (CK) activity (C), position sense at 45° elbow flexion (D), elbow joint reaction angle at 45° elbow flexion (E) and force match at 30% of pre-exercise maximal isometric contraction torque (F) before (Pre), and 0.5, 24, 48, 72, 96 and 120 h after 12 sets of 6 maximal eccentric contractions of the non-dominant elbow flexors for the far-infrared radiation (FIR) and sham treatment groups. * indicates a significant ($P < 0.05$) interaction effect by mixed-design two-way ANOVA. # indicates a significant ($P < 0.05$) difference between groups for each time point based on the post-hoc tests. † indicates a significant ($P < 0.05$) difference from the baseline.

markers returned to the baseline by 3–4 days after exercise; however, in the sham condition, they did not recover to the baseline even at 5 days post-exercise (Figures 2 and 3). This faster recovery of muscle function with the FIR therapy is practically important. It should be also noted that the extent of peak DOMS was approximately 60% smaller with the FIR therapy, and DOMS was subsided by 4 days post-exercise for the FIR condition, but still existed at 5 days post-exercise for the sham condition.

Since it has been reported that the magnitude of muscle damage is less for leg than arm muscles (Chen et al., 2011; Paschalis et al., 2010), the present study investigated two muscle groups to see whether the FIR therapy effects on muscle damage recovery, if any, would be similar between the EF and KF. The present study found that the magnitude of changes in MVC torque, DOMS, and FM at 30% MVC was significantly greater for the EF than KF. However, the effects of the FIR therapy on the muscle damage and proprioception markers were relatively similar between the EF and KF. When compared with the sham treatment condition, MVC torque recovery at 3 days post-exercise was enhanced by 12% for the EF and 7% for the KF, peak DOMS was reduced by 40% for the EF and 42% for the KF, and peak plasma CK activity was reduced by 89% for the EF and 83% for the KF by the FIR therapy (Figures 2 and 3). Thus, the FIR therapy appeared to work similarly for the EF and KF, but it should be noted that two FIR lamps were used for the KF, because of its surface area is approximately twice as large as that of EF. It is interesting to investigate the same effects would be induced if only one FIR lamp is used.

When comparing the effects of the FIR therapy found in the present study with those in which other phototherapy treatments such as low-level laser therapy (Fritsch et al., 2016), light-emitting diode therapy (Chang et al., 2021), and diodes therapy (Douris et al., 2006), the effects on the muscle damage parameters found in the present study appear to be much greater. For example, the present study found that all muscle damage and proprioception markers showed faster recovery by 1–3 days post-exercise with the FIR

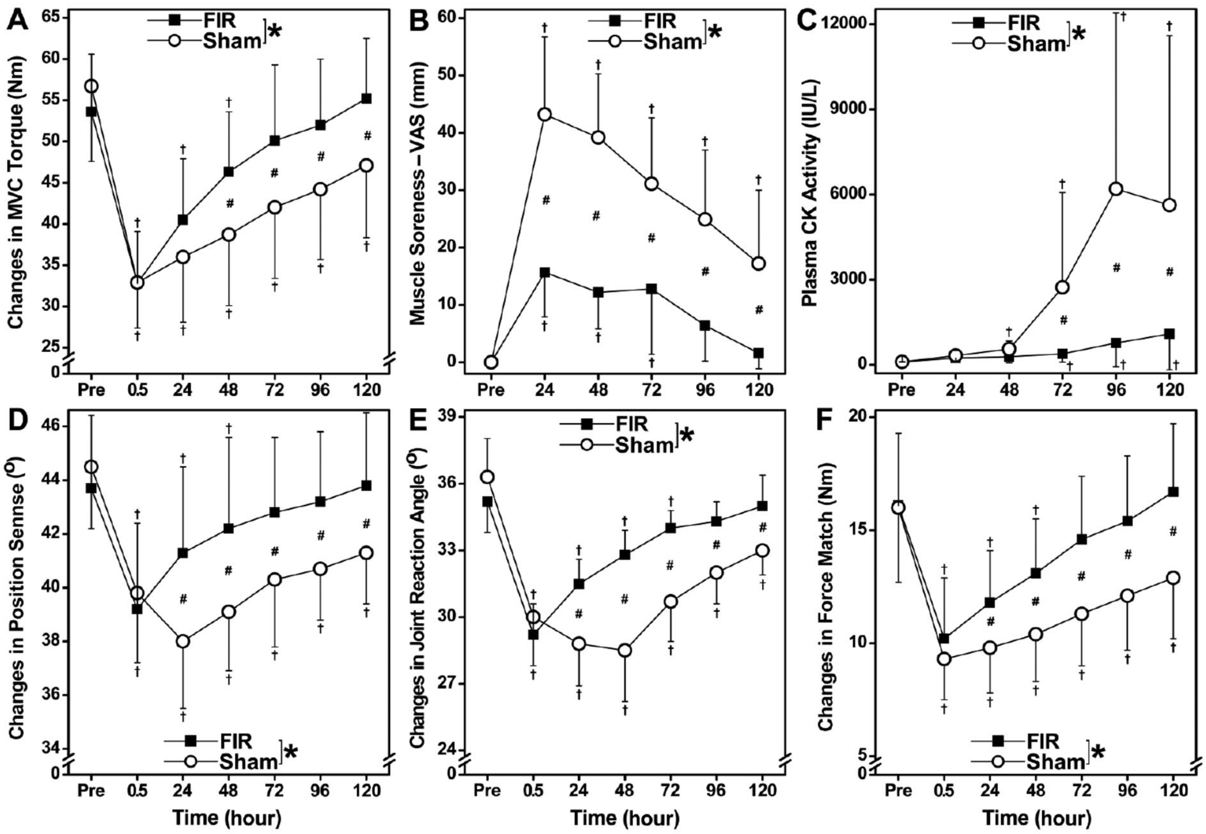

Figure 3. Changes in maximal voluntary isometric contraction (MVC) torque (A), muscle soreness (B), plasma creatine kinase (CK) activity (C), position sense at 45° knee flexion (D), knee joint reaction angle at 45° knee flexion (E), and force match at 30% of pre-exercise maximal isometric contraction torque (F) before (Pre), and 0.5, 24, 48, 72, 96 and 120 h after 10 sets of 10 maximal eccentric contractions of the non-dominant knee flexors for the far-infrared radiation (FIR) and sham treatment groups. * indicates a significant ($P < 0.05$) interaction effect by mixed-design two-way ANOVA. # indicates a significant ($P < 0.05$) difference between groups for each time point based on the post hoc tests. † indicates a significant ($P < 0.05$) difference from the baseline.

treatment, but this has not been observed in the previous studies (Chang et al., 2021; Douris et al., 2006; Fritsch et al., 2016). Therefore, to enhance muscle damage recovery and attenuate symptoms of muscle damage, the FIR lamp therapy could provide potent effects. It is also important to note that the FIR lamp therapy was simple, safe, non-invasive, and painless. Thus, it appears that the FIR lamp therapy is useful for individuals who wish to recover from MaxEC faster, especially for athletes who need to recover faster from matches and training (Hsieh et al., 2022).

The present study was not designed to examine the mechanisms underpinning the FIR lamp therapy effects on muscle damage and impaired proprioception recovery, but some speculations can be made. Leung (2015) listed several effects of FIR therapy based on in-vivo and in-vitro studies, such as increased nitric oxide (NO), calmodulin induction, intracellular heat shock proteins, antioxidant effects, and anti-inflammatory and pain relief effects with prostaglandin E_2 production. It seems possible that the daily 30-minute FIR therapy in the present study provided some of these effects on muscle fascia, fascicles, muscle fibers and connective tissue surrounded them. These may have enhanced the recovery from muscle damage by increased circulation, induction of NO and HSP as well as calmodulin upregulation, which positively affected tissue regeneration. Further studies are warranted to investigate the mechanisms.

There were several limitations in the current study. Firstly, the current study used young healthy sedentary women, thus the findings of the current study could not be directly generalised to other populations. Secondly, the changes in ovarian hormone status of these women during the study were not recorded, and the possible effects of the hormones on the outcome measures were not controlled. Thirdly, the outcome measures that were used in the present study were indirect markers of muscle damage. Thus, histological changes in muscle fibers, fascicles and connective tissues surrounding them were not known, thus the effects of the FIR lamp therapy on these architectures should be investigated in future studies. Future studies are warranted to consider these limitations and investigate whether the recovery of muscle damage and proprioception from a damaging exercise or a sport would be enhanced by the FIR lamp therapy, and explore the mechanisms. It is also interesting to investigate the effects of the FIR lamp therapy on hamstring strains.

In conclusion, the results of the present studies for two different muscle groups showed that the FIR lamp therapy enhanced the recovery rate from muscle damage induced by unaccustomed eccentric exercise, when the 30-minute FIR lamp treatment was provided at 1 h after exercise, and every 24 h for 4 days thereafter. It appears that the FIR lamp therapy is effective for alleviating muscle damage and impaired proprioception induced by eccentric exercise, but the mechanisms underpinning the effects require further studies.

Acknowledgements

The authors acknowledge Mr. Chung-Chan Hsieh, Ms. Xin-Rou Li and Ms. Yong-Yu Guo for they assistance in the data collection. The authors also would like to thank the study participants, and Professor Kuo-Wei Tseng (PT, PhD) for providing the far-infrared radiation and sham treatments to the participants.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was financially supported by the Ministry of Science and Technology [grant number MOST 108-2410-H-003-116-MY3 & 111-2410-H-003-147-MY3] and the Higher Education Sprout Project by the Ministry of Education (MOE) in TAIWAN. However, the funding organisations played no roles in the design of the study, and collection, analysis, and interpretation of the data and in writing the manuscript.

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