The Effects of Six Weeks of Deep-Water Running after Soccer Practice Combined with Plyometric Training on Indirect Symptoms of Muscle Damage

Apiluk Theanthong¹,*, Ratree Runghai¹, Apasara Arkarapanthu¹ and Thyon Chentanez²

ABSTRACT

This study examined the effects of deep-water running for 6 wk after soccer practice combined with plyometric training on the indirect symptoms of muscle damage. Thirty soccer players were divided into three groups—the control group (CON) performed stretching, the experimental group I (DWR) performed deep-water running combined with stretching, and the experimental group II (JOG) performed jogging combined with stretching. Individuals in each group performed different activities for 25 min after their daily training program. The creatine kinase levels in the CON group showed a significant \( P < 0.05 \) increase from the DWR group at 12 hr, 84 hr and at week 6. The lactate dehydrogenase levels in plasma changed significantly \( P < 0.05 \) in both the CON and JOG groups at 84 hr post-training. The drop jump and countermovement jump values after training were below the pre-training baseline \( P < 0.05 \). The maximum voluntary isometric contraction force and ankle extension range of motion (ROM) in the DWR group changed significantly \( P < 0.05 \) from pre-training throughout the period. The ankle flexion ROM in the DWR and JOG groups at 24 hr, 96 hr, week 5 and week 6 was significantly \( P < 0.05 \) above the pre-training baseline, while muscle soreness increased significantly in all groups at 24 hr and 96 hr post-training.

Keywords: stretch-shortening cycle, deep-water running, vertical jump, creatine kinase, lactate dehydrogenase

INTRODUCTION

Soccer is a sport that has various forceful and explosive actions, such as sprinting, jumping, turning, changing pace, changing direction and kicking (Reilly et al., 2000; Sedano et al., 2009). It involves an efficient, rapid transition from eccentric to concentric contraction called the stretch-shortening cycle (Komi, 2000). Muscle length during any stretch-shortening exercise is an important factor because it induces muscle damage (Marginson et al., 2005; Howatson and Milak, 2009). Exercise-induced muscle damage has been evaluated both directly and indirectly. However, direct evaluation is difficult because it is only possible through the analysis of muscle biopsies or through magnetic resonance imaging. The indirect evaluation of muscle damage has been utilized in human studies (Clarkson and Hubal, 2002; Ahmadi, 2007). Previous studies have...
reported that indices of indirect muscle damage were increased after soccer matches and training sessions (Andersson et al., 2008; Ascensão et al., 2008; Lazarim et al., 2009). Recently, modern soccer practices have been combined with explosive training to enhance the performance of both amateur and professional players (Ronnestad et al., 2008; Meylan and Malatesta, 2009).

Marginson et al. (2005) and Tofas et al. (2008) found increased biochemical indices of muscle damage and decreased vertical jump performance and muscle strength for 24 to 72 hr after plyometric training. The severity of muscle damage was due to the training load in such categories as high intensity, long duration and unaccustomed training (Clarkson, 1992).

Indirect methods of evaluating muscle damage have been used in several studies that included measuring changes in creatine kinase (CK) and lactate dehydrogenase (LDH) in plasma, maximal isometric voluntary contraction (MVC) force, drop jump (DJ) height, counter movement jump (CMJ) height, range of motion (ROM) and perceived muscle soreness (SOR). For all parameters, a time of peak change that induced muscle damage was found to be 24 to 72 hr post-training (Kobayashi et al., 2005; Skurvydas et al., 2006; Ahmadi et al., 2007). Therefore, the training load augmented by plyometric training within soccer practice may induce muscle damage and reduce a player’s performance.

Appropriate recovery is important to decrease fatigue, attenuate muscle damage, enhance the recovery process and enable training with greater efficiency in the next training session. Therefore, recovery can be considered a significant component of athletic training and performance (Coffey et al., 2004; Gill et al., 2006).

Common recovery methods used after soccer practice include jogging, massage, stretching, compression garments and aqua exercise (Tessitore et al., 2007). More specifically, deep-water running is an easy method that several studies (Chu and Rhodes, 2001; Reilly et al., 2003) have used to reduce stress and accelerate recovery after stretch-shortening exercise, soccer matches and competitions. This method reduces loading impact on the body by providing water buoyancy. These studies have sought to examine recovery from muscle damage after soccer matches, between training sessions or between consecutive matches. However, recovery from muscle damage after daily training sessions by deep-water running for several weeks has not been previously examined. Therefore, the aim of the present study was to examine the effects of a six-week trial of deep-water running after soccer practice combined with plyometric training on the indirect symptoms of muscle damage. It was hypothesized that six weeks of deep water running would have different effects on the indices of indirect symptoms of muscle damage among the three treatment groups.

**MATERIALS AND METHODS**

**Subjects**

The subjects were 30 volunteer male soccer players from the Kasetsart University Kamphaeng Saen Campus Soccer Club. The subjects had participated in soccer practice for 1–2 yr, had no musculotendinous injury, and goalkeepers were excluded. The subjects were divided randomly into three groups; all soccer players practiced a regular soccer program and followed a specific group recovery method. The control group (CON) performed stretching, experimental group I (DWR) performed deep-water running combined with stretching, and experimental group II (JOG) performed jogging combined with stretching. The physical characteristics among the groups are shown in Table 1. All subjects were informed about the study procedures, the associated risks and benefits of the study and they all gave written consent before the investigation. The study protocol was approved by the Ethical Review Committee for Research in Human Subjects, Ministry of Public Health, Thailand.
Experimental design

This study included 6 wk of daily deep-water training after soccer practice combined with plyometric training to attenuate muscle damage in soccer players. Creatine kinase (CK) and lactate dehydrogenase (LDH) were tested 2 d before training, after 12 hr, 84 hr and 6 wk post-training. Measurements of the maximum voluntary isometric contraction force (MVC), drop jump (DJ) and countermovement jump (CMJ) heights, ankle range of motion (ROM) and muscle soreness (SOR) were collected 2 d before training (pre-training) and after training at 24 hr, 96 hr and at the end of each week. The test subjects were given a rest on Saturday and tested on Sunday each week (weeks 1 to 6).

All subjects engaged in the regular soccer training program of the Kasetsart University Kamphaeng Saen Campus Soccer Club five times a week (Monday through Friday evenings) for 6 wk. They practiced 90 min of soccer drills, and the teams played on Tuesday, Wednesday and Friday. Thirty minutes of plyometric training (including lateral jumping, multiple jumping, vertical jumping and drop jumping) were performed before 60 min of soccer drills on Monday and Thursday. Subjects performed different recovery activities after their training program. The CON group completed 25 min of stretching, the DWR group completed 15 min of running at 40% heart rate reserve (HRR) in a water depth 2.5 m and 10 min of stretching in the water (water temperature average $28.9 \pm 0.8 ^\circ C$) with subjects using foam belts around their waists and feet to prevent them from touching the base of the swimming pool during movement. The JOG group completed 15 min of jogging at 40% HRR and 10 min of stretching. All groups performed stretching using a similar technique, focusing on the ankle and knee extensor and flexor muscle groups. Testing was completed in the following fixed order at the same time for each testing session: muscle soreness, plasma CK and LDH activities, ankle range of motion, maximum voluntary isometric contraction force of the gastrocnemius muscle, drop jump height and countermovement jump height.

Muscle Soreness (SOR)

Prior to taking blood samples, each subject was asked to indicate the level of gastrocnemius muscle soreness with the heel raised and walking using a visual analog scale of 1 (no pain) to 7 (very, very painful) described by Sayers et al. (2000).

CK and LDH activities

Approximately 4 mL of blood was drawn from an antecubital vein and stored on ice in heparinized tubes for further analysis. Plasma CK and LDH (U/L) were analyzed using the COBAS INTEGRA system (Roche Diagnostics, GmbH, Mannheim, Germany). The normal reference ranges of CK and LDH activities using this instrument are 38–174 U/L and 240–480 U/L, respectively.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical characteristics of subjects (mean ± SD).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON group (n = 10)</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>21.10 ± 1.66</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.10 ± 6.11</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.70 ± 5.59</td>
</tr>
<tr>
<td>Body mass index (kg.m$^{-2}$)</td>
<td>21.23 ± 1.61</td>
</tr>
</tbody>
</table>

CON = control group, performed stretching only; DWR experimental group I, performed deep-water running combined with stretching; JOG = experimental group II, performed jogging combined with stretching.
Range of Motion (ROM)

Ankle ROM (plantar flexion and dorsiflexion) in the dominant leg was assessed with the subject sitting on the end of a table with the knee flexed and ankle positioned at 90° using a universal goniometer (Jarma 360°; Patterson Medical; Bolingbrook, IL, USA). The procedure for this testing was a modification of that described by Heyward (2006). The average of two trials of ROM was used for data analysis. The reliability of the coefficient for repetitive measurement was 0.89.

Maximum Voluntary Isometric Contraction force (MVC)

The maximum voluntary isometric contraction force of the gastrocnemius muscle was measured at an ankle joint angle of 30° in the dominant leg using an isokinetic dynamometer (Biodex System 3 PRO; Biodex Medical Systems; Shirley, NY, USA). The dynamometer was set up according to the instrument’s manual. All subjects completed an ankle plantar flexion two times for 5 s (90 s between each measurement). The peak MVC from the two contractions was used for data analysis.

Vertical jump performance

The drop jump (DJ) and countermovement jump (CMJ) heights in the vertical jump performance test used a force mat (Newtest; Tynävä, Finland). The DJ was performed from a 40 cm box height. Subjects stepped from the box and landed on the force mat with both feet. They were asked to jump immediately upward as high as possible. The CMJ was performed from an erect standing position with knees fully extended on the force mat. After a one-word verbal command, subjects made a downward countermovement with a knee joint angle of 90° and then jumped upward as high as possible. Subjects were instructed to hold their hands on their waists during the vertical jump test. Each test was performed twice (with 60 s of recovery between trials and between different types of jumps) and the means of the two measurements were used for data analysis.

Statistical analysis

The results were presented as means ± SE. The Kolmogorov-Smirnoff test examined the distribution of all dependent variables and found no significant differences compared with normal. The reliability of ankle ROM assessment was verified using an intraclass correlation coefficient. A two-way analysis of variance (ANOVA) with repeated measures was used to analyze the group-time interactions and to examine significant differences between groups and within groups. Each dependent variable changed at different time points and was compared using a one-way ANOVA with repeated measures. A least significant difference post hoc test was conducted if significant main effects or interactions were found. Statistical significance was tested at the $P < 0.05$ level.

RESULTS

CK and LDH Activities

At pre-training, the absolute CK activity showed no significant differences between the DWR, JOG and CON groups, averaging 160.60 ± 5.93, 156.80 ± 6.65 and 158.90 ± 6.59 U/L, respectively. Compared with the pre-training value, the CON group registered a significantly greater change and difference than the JOG and DWR groups at all measured times and reached a peak at 84 hr post-training. After week 6, the only significant difference from the pre-training value was in the DWR group (Figure 1A).

LDH activity at the pre-training measurement time in the DWR, JOG and CON groups averaged 298.30 ± 9.56, 280.40 ± 24.85 and 281.90 ± 17.83 U/L, respectively. Compared with the pre-training value, the CON and JOG groups had significantly increased LDH activity at 84 hr post-training. After week 6, the LDH activity
in the DWR group decreased below the baseline and registered a difference from the CON group (Figure 1B).

**Maximum voluntary isometric contraction force**

The maximum voluntary isometric contraction force (MVC) of the gastrocnemius muscle before training in the DWR, JOG and CON groups averaged 92.10 ± 3.59, 104.70 ± 5.76 and 89.10 ± 4.97 Nm, respectively. The DWR group showed a significantly ($P < 0.05$) greater increase in the MVC compared with pre-training at all testing periods and registered a significant difference from the JOG group at 96 hr, week 5 and week 6 (Figure 2).

![Figure 1](image)

**Figure 1** Normalized changes in creatine kinase (A) and lactate dehydrogenase (B) from the pre-training level (100%). Data are presented as mean ± SE. DWR = deep-water running group, JOG = jogging group, CON = control group. Pre = pre-training, 12 hr = 12 hours after training, 84 hr = 84 hours after training, 6 wk = 6 weeks after commencing training. * = Significant difference from the CON group at the same time point. # = Significant difference from the JOG group at the same time point. a = Significant difference from the pre-training value within a group.
Vertical jump performance

The vertical jump performance changes are shown in Figure 3. The DJ height before the training program in the DWR, JOG and CON groups averaged 30.90 ± 0.61, 31.66 ± 1.15 and 34.14 ± 1.01 cm, respectively. All three groups declined at 96 hr and at week 4 post-training. In particular, the CON group remained below the baseline until week 6. Before the training program, the CMJ of the DWR, JOG and CON groups averaged 35.58 ± 0.95, 36.64 ± 1.59 and 38.13 ± 0.88 cm, respectively. The pattern changed over the entire post-training period, similar to the DJ results, with each group having the greatest decline at 96 hr post-exercise.

Range of motion

Ankle extension ROM in the DWR, JOG and CON groups prior to training averaged 36.10 ± 1.42, 33.80 ± 1.46 and 36.60 ± 1.48 degrees, respectively. Compared with the pre-training data, all groups increased (P < 0.05) over time (Figure 4A). ROM for ankle flexion prior to training in the DWR, JOG and CON groups averaged 12.70 ± 0.79, 15.50 ± 0.69 and 14.70 ± 0.56 degrees, respectively. Compared with the pre-training data, the ankle extension ROM in the DWR group increased (P < 0.05) at 24 hr, 96 hr and at weeks 2, 4, 5 and 6 post-training (Figure 4B).

Muscle soreness

Compared with the baseline data, muscle soreness in the three groups increased (P < 0.05) at 24 hr and 96 hr after the training and returned to near baseline during weeks 1, 2 and 3. Then, SOR increased (P < 0.05) again at week 5 after training (Figure 5).

DISCUSSION

The present study investigated the different indirect symptoms of muscle damage adaptation during a six-week period after soccer...
practice combined with plyometric training for three groups—namely, deep-water running (DWR), jogging (JOG) and stretching (CON). Recovery activities after daily training are of great importance for reducing muscle strain and damage. This recovery helps to increase the efficiency of training in subsequent sessions. CK and LDH activities in plasma indicate muscle damage, and both were significantly increased after stretch-shortening exercise (Komi, 2000; Meylan and Malatesta, 2009). In the present study, CK activity in the plasma of subjects from the three groups demonstrated a significant increase at 12 hr and the highest normalized (defined as the change...
Figure 4 Normalized changes in ankle extension range of motion (ROM) (A) and ankle flexion ROM (B) from the pre-training level (100%). Data are presented as mean ± SE. DWR = deep-water running group, JOG = jogging group, CON = control group. Pre = pre-training, 24 hr = 24 hours after training, 96 hr = 96 hours after training, W1–W6 = 1–6 weeks after commencing training, respectively. * = Significant difference from the CON group at the same time point. # = Significant difference from the JOG group at the same time point. a = Significant difference from the pre-training value within groups.

relative to a level of 100% for the pre-training measurement) change at 84 hr after training. Previous studies (Andersson et al., 2008; Tofas et al., 2008) have shown that after plyometric training, soccer training, and soccer training combined with plyometric training, the indirect symptoms of muscle damage increased. However, after training, the CON group had a greater increase than the other groups over time. It is possible that stretching only increased the muscle damage. According to Reisman et al. (2005), stretching when membrane damage has occurred can lead
to the spread of sarcomere disruption, interference with the excitation-contraction coupling process and tearing of T-tubules. Similarly, Andersen (2005) has shown that stretching does not lead to injury reduction or reduced risk of injury. The DWR and JOG groups represented active recovery and stretching. Barnett (2006) reported that active recovery enhanced the recovery process by increasing the blood flow to the ruptured muscle cells. Hough (1902) noted that increased blood flow removed noxious waste products and induced nutrients to disrupted cells, thereby speeding up the healing process. After training for 6 wk, only the DWR group had CK activity that had returned to the baseline pre-training level and was different from the JOG and CON groups.

LDH activities in plasma showed similar variations to CK levels in the blood of all groups and peaked at 84 hr post-training. According to Clarkson and Hubal (2002), CK and LDH leak out of muscles because the cell membranes are destroyed, which results in peaks in CK and LDH approximately 12 hr to 6 d, post-exercise. This result suggests that soccer practice twice a week combined with plyometric training would induce muscle damage. Additionally, changes in CK and LDH activities paralleled increases in perceived muscle soreness. Nosaka and Clarkson (1996) demonstrated that the training load was reflected in structural disruption, increased intramuscular fluid pressure and activated free nerve endings in muscles, thereby contributing to the sensation of soreness. The present study confirmed that active recovery, such as deep-water running, acted to reduce muscle damage and enhanced the recovery process. Accordingly, Reilly and Ekblom (2005) have found that the properties of water reduced the impact of loading on the lower limbs and there was no eccentric contraction during movement in water; thus, no extended cell damage was observed during active recovery with a reduction of muscle soreness. However, the highest normalized change in LDH activity of all three groups (102.42–108.78%) was less than the highest normalized change in CK activity (218.41–320.37%). Su et al. (2010) have suggested that the molecules of LDH, which represent small amounts in the blood, are larger than the molecules of CK and

Figure 5 Normalized changes in muscle soreness from the pre-training level (100%). Data are presented as mean ± SE. DWR = deep-water running group, JOG = jogging group, CON = control group. Pre = pre-training, 24 hr = 24 hours after training, 96 hr = 96 hours after training, W1–W6 = 1–6 weeks after commencing training, respectively. a = Significant difference from the pre-training value within groups.
do not exit the cell as readily. After 6 wk, only the CK and LDH activities of the DWR group returned to the baseline. This result is supported by previous studies that found that muscle fibers are more resistant to training-induced muscle damage by myofibril adaptation, especially increased membrane stability, which increases the strength of muscle fibers and greatly encourages the recovery process (Chen, 2003; Howatson et al., 2007). Similarly, Reilly et al. (2003) have investigated deep-water running and that found it had potential to decrease the compressive force on the skeletal muscles and was effective in temporarily relieving muscle damage, while enhancing the recovery process.

The MVC of the gastrocnemius muscles for all three groups was increased 24 hr after training. It may have increased the slow twitch muscle fiber activation, which decreased the stress on the fast twitch muscles (Friden and Lieber, 2001). This result correlates with the fact that the stiffness of the muscles was reported to have a linear relationship to torque output (Cornu et al., 1997). Additionally, at 96 hr post-training, the MVC of the gastrocnemius muscle in the DWR and CON groups increased and was perhaps caused by muscles that were tightened after plyometric training on the day prior to the test but were of suitable tightness to increase muscle contraction. There was no activated force to increase damage to the muscles during the cool-down activities of both groups, which was different from the JOG group in which the force activating the muscles during running may have resulted in more damage to the muscles as indicated by increased CK and LDH levels after training. In addition, the contraction force also decreased ankle flexion ROM after training. This result demonstrates that the muscles were tighter. After the first week of training, it was noted that the DWR and CON groups had decreasing percentages of gastrocnemius muscle contraction, whereas the JOG group had a value close to the baseline. This change was related to fatigue from training, which reduced the capacity to exert force. After the completion of 6 wk of training, the DWR and CON groups had significantly different values from the baseline.

The DJ and CMJ heights decreased at 24 hr after training and decreased to their lowest values at 96 hr after training. These findings accord with previous studies (Morgan and Allen, 1999; Skurvydas et al., 2006) that have shown that after stretch-shortening exercise, the neuromuscular performance decreased for several days, because the ability to perform DJ or CMJ exercises originates from the mechanism of the actin-myosin cross bridge of the contractile component; it is also related to the microprotein that provides the stability of the sarcomere and to the protein (titin, nebulin, integrin, dystrophin and desmin) that binds the filament and the sarcomere. In addition, Brooks et al. (2005) reported that microprotein would increase the elastic energy upon stretching the muscle to follow the contractile component. It may contribute to damage to the elastic component, which was caused by plyometric training during soccer practice. This result was different from the result of the MVC test, which showed that 24 and 96 hr after training, the values of the three groups increased. In this regard, the muscles contracted isometrically in MVC testing, which was related to the contractile component. During weeks 1, 2 and 3 of training, the DWR and JOG groups both had values close to the before-training values because of the dynamic activities, especially running in water, which helped to attenuate muscle damage. During weeks 4 and 5 of training, the DJ and CMJ heights decreased as a result of muscle fatigue from the stretch-shortening cycle exercise in the training program (Avela and Komi, 1998), but they increased in the sixth week of training. This study has shown that plyometric training for 6 wk could increase the muscle power from the drop jump and counter movement jump tests, which corresponded with the study reported by Miller et al. (2006) who used plyometric training for 6 wk to
develop agility in athletes. Additionally, Reyment et al. (2006) found that plyometric training twice a week for four consecutive weeks could increase the height of single-leg vertical jumps for hockey athletes but was insufficient to decrease the time to run 10 m and 40 m. Furthermore, plyometric training increased the height of two-leg vertical jumps.

The ROM of ankle extension and flexion is related to movement, such as running and jumping in soccer games. Takahashi et al. (2006) considered that the gastrocnemius muscles demonstrated a reaction force from the floor greater than that of other muscles because the gastrocnemius is closest to the floor and only has a mild impact absorption interval. In addition, plyometric training increased contraction of the gastrocnemius muscles, which increased muscle tension after training (Cornu, 1997). Regular muscle stretching could help to develop better flexibility. The percentage ROM of ankle extension for all three groups was higher after training compared with before. The function of the anterior lower leg muscles results in less movement in training directed to the posterior lower leg muscles, so that contraction and damage from this training was slight and had no impact on decreasing ankle extension ROM. The percentage ROM of ankle flexion of the JOG group tended to be greater than for the DWR group because the posture of the stretched muscles in ground-based exercise was observed to be more stable than that of stretched muscles in water. Therefore, stretching targeted muscles to extreme or mild pain corresponds to the principles of stretching to develop flexibility of muscles (Heyward, 2006).

Muscle soreness of the three sample groups increased 24 and 96 hr after training. The soreness was caused by inflamed muscles after training, thus activating the sensation of pain, which decreased movement efficiency. Such a change corresponds to the increased levels of CK and LDH in the blood, but muscle pain levels decreased in weeks 1, 2 and 3 of training and then increased again in weeks 4, 5 and 6 of training. This corresponded with changes in the strength of extreme contraction of the gastrocnemius muscle and the DJ and CMJ heights, which were caused by damage to the muscles or fatigue that had accumulated over several consecutive weeks of training. However, after 6 wk of training, it decreased to a normal value and thus, no muscle pain was reported.

CONCLUSION

The results of this study demonstrate that deep-water running quickly removed creatine kinase. The drop jump and countermovement jump heights after deep-water running recovery were reduced less than after jogging and stretching activity. Therefore, the deep-water running that attenuates muscle damage, enhances the recovery process and enables training with greater efficiency in the next training session, when combined with plyometric training, may be an option for a post-exercise method after a soccer training program.

ACKNOWLEDGEMENTS

The authors would like to thank the Graduate School of Kasetsart University for supporting publishing, and the student soccer players for their participation in this study.

LITERATURE CITED


