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Muscle Damage Indicators after Land and Aquatic Plyometric Training Programmes

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ABSTRACT Plyometric training is an important part of athletic conditioning with many significant benefits, including improved motor abilities and performance, but it can also increase the serum indices of muscle damage, collagen breakdown, muscle swelling, and soreness. Due to the physical characteristics of water, plyometric training in water presents less eccentric contraction, facilitates faster transition from the eccentric to concentric phase of a jump and offers greater resistance during concentric contraction with acute lower indices of muscle damage. To advance our understanding of the long-term effects of an eight-week plyometric training programme on land and in water on muscle damage indicators (lactate dehydrogenase (LDH), creatine kinase (CK) and serum urea (SU)), two experimental groups of physically active men (a group on land (EG1) and a group in water (EG2)) were tested before and after the first and the last plyometric training to monitor muscle damage indicators and adaptations. The results showed changes in CK activity after both plyometric trainings for EG1 and only after the first training for EG2. Moreover, after the eight-week programme, significant difference was observed in CK activity in comparison with EG2. There were no observed changes in LDH activity while SU showed greater changes for the group on land. The plyometric training programme in water resulted in smaller levels of muscle damage indicators. Although both experimental groups conducted the same plyometric training with the same jump volume, the eccentric and concentric loads were not the same, so it can be concluded that adaptations in muscle damage processes are faster with smaller eccentric loads.

KEY WORDS Plyometric training programme, water plyometrics, muscle damage, lactate dehydrogenase, creatine kinase, serum urea

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Introduction

Plyometrics is a form of training that represents a fundamental and significant aspect of physical conditioning in numerous team and individual sports, while moderate load eccentric exercise is also used in rehabilitation for different medical issues (Hoppeler, 2016). During plyometric motor patterns, such as jumping, running, hopping, etc., the stretch-shortening cycle (SSC) plays a key role in improving strength, power, speed, joint function and stability, balance and neuromuscular control during landing (Donoghue et al., 2011; Marković & Mikulić, 2010; Martel et al., 2005). Although there are many benefits of plyometric training, studies have shown that plyometric exercises can increase the serum indices of muscle damage, collagen breakdown, and muscle swelling and soreness (Kamadulis et al., 2011; Komi, 2000; Miyama & Nosaka, 2004; Tofas et al., 2008); they can also attenuate muscle function and cause musculoskeletal injuries, especially of the lower extremities (Serrao, 2003). This often happens in programmes in which the overuse of plyometric exercises is involved, as well as in cases with inappropriate levels of plyometric motor patterns. It is well documented that the greatest muscle damage occurs after eccentric exercises, primarily after ones to which the athlete is unaccustomed, whether the cause is the type, the duration or the intensity of the exercise itself (Schoenfeld, 2012). Eccentric contraction during plyometric exercises can generate high tensions per myofibre that lead to alterations in motor unit recruitment and result in muscle fibre damage. For a long time, it was considered that the greater the damage, the greater would be muscle adaptations such as muscle hypertrophy; however, there is now evidence that proofs that every muscle has a threshold after which further damage does not augment muscle remodelling (Schoenfeld, 2012). Regarding that

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fact, plyometric training in water could probably present an optimal load with less muscle damage (Donoghue et al., 2011; Marković & Mikulić, 2010; Martel et al., 2005; Robinson et al., 2004). It is important to be aware that a certain type of plyometric exercise, upon considering the type and the number of contacts with the ground, does not present the equal volume and intensity when performed in water and on land. Studies of plyometric training in water have shown statistically significant improvements in motor abilities and performance (Martel et al. 2005; Miller et al., 2002; Miller et al. 2007; Robinson et al., 2004; Shiran et al., 2008; Stemm & Jacobson, 2007). There are several studies showing that muscle stress and damage indicators are lower after aquatic plyometric training in comparison to the identical training on land (Miller et al. 2007; Pantoja et al., 2009; Stemm & Jacobson, 2007). In addition, there is also certain evidence regarding lower muscle damage indicators in water and on land after plyometric training programmes (Robinson et al, 2004; Shiran et al., 2008).

Monitoring muscle damage indicators plays a vital role in controlling the physiological and training status of athletes, while muscle adaptation to physical load is associated with an improved regulation of enzyme activity and stress indicators (Brancaccio et al., 2006; Brancaccio et al., 2007; Butova & Masalov, 2009). Therefore, the purpose of the present study was to compare muscle stress (serum urea (SU)) and muscle damage indicators (lactate dehydrogenase (LDH) and creatine kinase (CK)) after a single plyometric training session and after an eight-week plyometric training programme performed in water and on land.

Material and Methods

Data collection

With the aim of monitoring the influence of a plyometric training programme on muscle stress and muscle damage indicators, blood analysis was conducted in two experimental groups of twenty male kinesiology students. Blood parameters were measured four times, before and after the first and last training session of the eight-week training programme. Basic anthropometric parameters were also measured to prove the absence of statistical differences between the two experimental groups. All tests were performed at the Sports Diagnostic Centre of the Faculty of Kinesiology, while the programme was conducted in the large sports hall of the Faculty of Kinesiology and at the swimming pools of the "Mladost" Sports Recreation Centre in Zagreb. This training programme included unilateral and bilateral plyometric exercises (Ankle jumps, Countermovement jumps; Drop jumps (30 cm), Single leg ankle hops, Single leg countermovement jumps, Single leg forward jumps, Alternate-leg bounds, Single leg lateral hops, Lateral bounds) with progressive loading from 150 to 200 contacts with the ground, as recommended by Potach and Chu (2000). The experimental group in water (EG2) conducted the programme in water at hip-depth level with arms positioned on hips, while the experimental group on land (EG1) conducted the programme in a gym hall with arms positioned on hips. To monitor the effects of land and water plyometric training programme on performance, six motor performance parameters were measured before and after completion of the plyometric programme. Speed was assessed using the time for a 5-metre sprint running (v5), 10-metre sprint running (v10) and 20-metre sprint running (v20) which were measured using a photocell system (Newtest, Finland). Agility, also referred as change of direction speed was assessed using the time for running 20 yards (20y) with two changes of direction. Explosive power was assessed using height for a standing vertical jump (VJ) and length for a standing horizontal (long) jump (SLJ).

Each participant was informed about the aim of the study and gave written consent for participation in the study. The protocol of the study was approved by the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, in accordance with the Declaration of Helsinki.

Participants

Twenty healthy and physically active male second-year students at the Faculty of Kinesiology, University of Zagreb, were randomly divided into two experimental groups. No history of injury was reported in the previous six months. The first experimental group (EGL: n=10) participated in the eight-week plyometric training programme on land, and the second experimental group (EGW: n=10) participated in the same plyometric training programme but carried out in water. Both experimental groups underwent 16 identical training sessions (two per week). They were all instructed not to include any other activity during the training programme.

Blood sampling and analysis

Blood samples were taken from the cubital vein, and the samples were immediately centrifuged (StatSpin® Express 2). Further analysis of the blood serum was performed with a biochemical analyser (Olympus AU480®) based on the recommendations of the International Federation of Clinical Chemistry (IFCC). Blood was taken one hour before the first and last training sessions in the plyometric programme, as well as 24 hours after the first and last training sessions.

One of the blood parameters that was tested was lactate dehydrogenase (LDH), which is the enzyme responsible for catalysing glycolytic reactions, conversion of pyruvic acid to lactate acid and reversible action. The activity of serum LDH is important and very often used as a biochemical diagnostic method for monitoring muscle tissue and its damage in sports. The normal level of LDH in blood serum is up to 241 U/l; however, the level of serum LDH in athletes can be lower before a physical load when compared to non-athletes (Eiras et al., 2009). It is documented that LDH can increase from 30% to 200% depending on the intensity of the plyometric training or, more precisely, depending on eccentric contractions, and it can remain elevated for 24 to 72 hours (Chatzinikolaou et al., 2010; Eiras et al., 2009; Tofas et al., 2008).

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The second parameter that was tested was creatine kinase (CK). The elevated activity of this muscle damage marker, which typically does not leak out of non-damaged cells, has been used as a marker of the functional status of muscle tissue, and it varies widely in both pathological and physiological conditions (Lee et al., 2002). Although the normal level of CK in blood serum can be up to 177 U/l, reference intervals for athletes can be 82–1083 U/l and 47–513 U/L for male and female athletes, respectively (Mougios, 2007). Blood CK activity can peak from 24 to 72 hours after strenuous eccentric exercises.

The third measured parameter was the serum urea as an indicator of fatigue and oxidative stress. Concentrations between 1.7 and 8.3 mmol/l are referred to as normal; however, there is no evidence that the mentioned levels can be attributed to athletes (Hartmann & Mester, 2000).

Statistical analysis

All statistical analysis was performed using STATISTICA 10.0 (StatSoft, USA). The results were expressed as the mean and standard deviation (X±SD). Due to a relatively small sample size, all data were presented and treated as not normally distributed, so nonparametric analyses were performed. The Mann-Whitney U-Test was used to determine the differences in parameters between the two groups, while the Wilcoxon Matched Paired Test was used to determine the differences before and after the first and second measurement of blood parameters in both groups. The level of significance (p) was set at 0.05 for all analyses.

Results

All participants completed the eight-week plyometric training programme without any reported injuries. During the programme, there were complaints of muscle soreness among the participants, which was an expected reaction to intensive eccentric and concentric muscle action, especially for the experimental group on land. The basic anthropometric status of the participants is outlined in Table 1.

TABLE 1 Descriptive statistics of participants' anthropometric status

GROUP	Number of participants	Age (years)	Body Mass (kg)	Body Height (cm)	Body Fat (%)
EGL	10	22.33 ± 2.06	79.10 ± 9.24	180.27 ± 7.31	12.34 ± 4.75
EGW	10	21.90 ± 1.73	81.68 ± 10.24	178.58 ± 6.27	13.47 ± 6.21

Note: Values are presented as mean ± standard deviation (X ± SD); EGL - experimental group on land; EGW - experimental group in water.

Figure 1 shows the statistical differences in CK levels in both experimental groups as resulting from the non-parametric Wilcoxon Matched Paired Test. The results of the experimental group on land show differences before and after both plyometric trainings (1st - 277.33±101.93 (pre) – 551.74±283.50 (post); 2nd - 250.17±64.89 (pre) – 515.59±327.74 (post)), probably because of high eccentric contraction during the plyometric training. The results of the experimental group in water also show significant differences before and after both plyometric trainings, but with somewhat lower CK levels (1st - 263.89±119.08 (pre) – 486.21±369.92 (post); 2nd - 226.51±101.02 (pre) – 310.73±136.82 (post)).

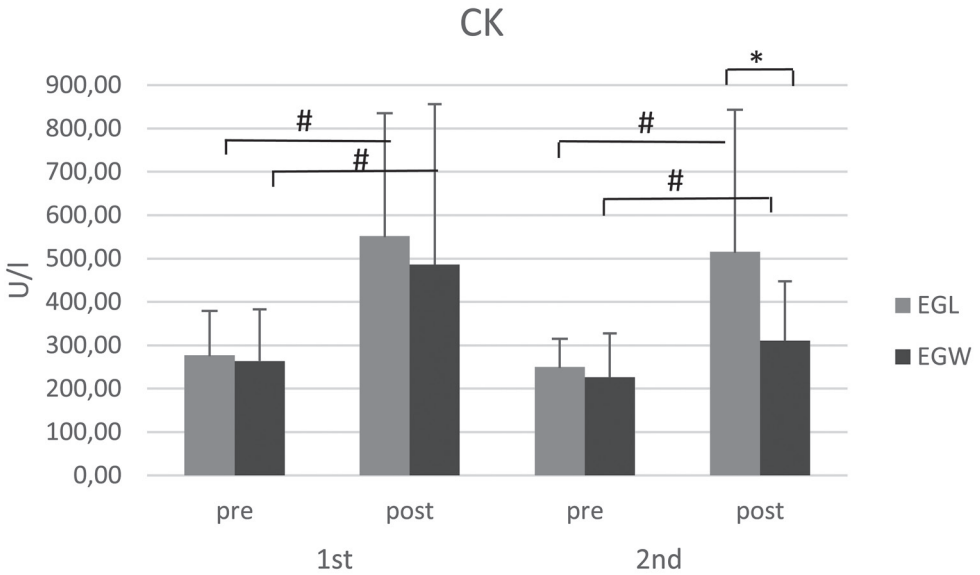

FIGURE 1 Creatine kinase results before (pre) and after (post) the first (1st) and last (2nd) plyometric training sessions

Note: * indicates a significant difference (p<0.05) between the results of the two experimental groups; indicates a significant difference (p<0.05) between the results before (pre) and after (post) the plyometric training session.

The Mann-Whitney U Test showed only one significant difference between the groups and that was in the level of CK activity after the last training session (2nd post measurement) (Z=2.29, p=0.03).

No other differences in CK activity were observed between the experimental groups, nor were there any significant differences in LDH levels in the blood serum observed before and after the first and last plyometric training session, or between the two groups in any measurement (Figure 2).

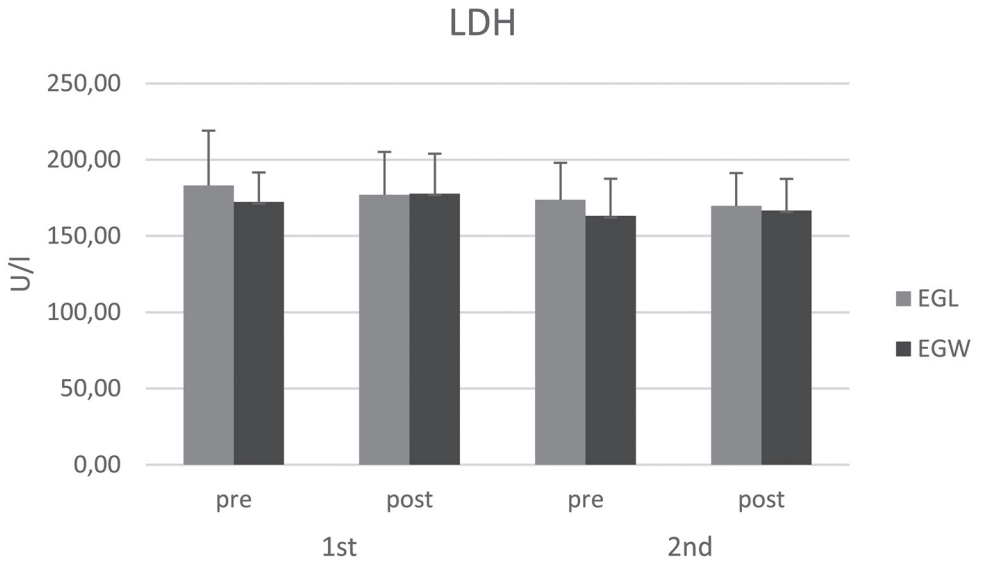

FIGURE 2 Lactate dehydrogenase results before (pre) and after (post) the first (1st) and last (2nd) plyometric training session

The only statistically significant difference in SU was a change after the first plyometric training session in the experimental group on land (Z=2.50, p=0.01) (Figure 3). Regarding the levels of SU, most of the results were within the interval, which is referred to as normal (1.7 – 8.3 mmol/L). No other significant differences in SU were observed between the two experimental groups. The plyometric training programme on land has shown improvement on three motor performance variables (v10, v20, and VJ), while the plyometric training programme in water influenced all motor performance variables except the standing long jump (SLJ). Both treatments resulted in greater motor performance, while EGW showed greater improvement due to water plyometrics.

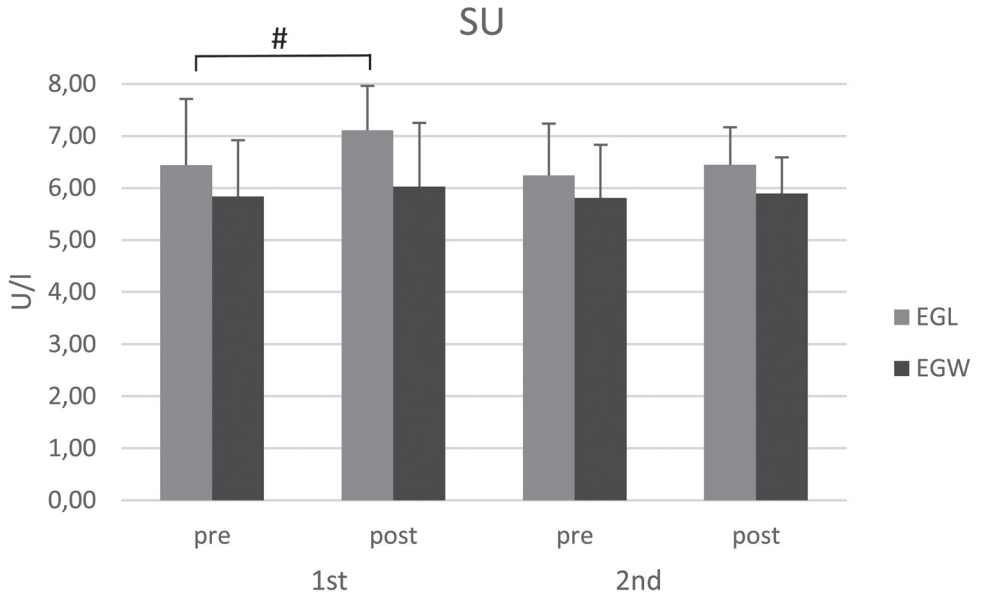

FIGURE 3 Serum urea results before (pre) and after (post) the first (1st) and last (2nd) plyometric training session
Note: # indicates a significant difference (p<0.05) between the results before (pre) and after (post) the plyometric training sessions.

Discussion

The purpose of the present study was to compare the effects of plyometric training on muscle damage markers after two plyometric training sessions, one at the beginning and the second after an eight-week plyometric

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training programme in water and on land. It is known that strenuous plyometric training can damage the muscle cell membrane, which can result in the leakage of CK and LDH and generate a delayed onset of muscle soreness (DOMS) (Clarkson et al., 2005; Lee et al., 2002; Shiran et al., 2008). The aquatic environment has demonstrated less change in muscle damage indicators due to slower and less intensive eccentric contraction and a more rapid neuromuscular recovery (Pantoja et al., 2008; Robinson et al., 2004; Shiran et al., 2008). The main finding of this study is that land plyometrics showed a significant difference in CK activity after both training sessions, both at the beginning of the programme, as well as after the eight-week programme in comparison with water plyometrics. The results showing 198.98% and 206.09% higher levels of CK in EGL indicate the possibility that there were no adaptations to plyometric training after the eight-week programme; however, the fact that this study showed a large standard deviation, a relatively small sample and variability of the measured variables (CK and the others) indicates the need for individual interpretations of the results (Hecksteden et al., 2006). Totals of 184.24 % and 137.18% higher levels of CK in EGW also demonstrate the acute effect of strenuous plyometric training sessions; however, minor changes after the eight-week programme reflect the possibility of a faster adaptation to the lower eccentric intensity.

The authors presume that the participants of the study could adapt sooner to the lower intensity, which was a result of a lower level of muscle damage during the programme conducted in water. This conclusion also raises the question of the comparative value of the two identical plyometric programmes, but with a lower eccentric intensity for the one in the water. In previous studies, the conclusion was made that the aquatic plyometric training programme showed no significant differences in motor performance and motor abilities effects compared to the plyometric training programme on land (Miller et al., 2002; Miller et al. 2007; Shiran et al. 2008; Stemm & Jacobson, 2007). Kobak and his colleagues (2015) demonstrated that the eight weeks of water-based plyometrics resulted in significant improvements in balance, vertical jump height, and isokinetic strength. Therefore, if there is a possibility to improve performance with lower levels of muscle damage (CK activity), there is no reason for aquatic plyometrics not to be incorporated in different periods of physical conditioning for athletes.

While CK activity was high, there were no differences in LDH activity between the two experimental groups, before and after the plyometric training sessions within each separate experimental group. In their study conducted with wrestlers, Shiran et al. (2008) also demonstrated significant results in CK activity in the blood, but with no significant differences in LDH activity. Previous studies have confirmed that LDH can remain elevated for 24 to 72 hours after high-intensity plyometric training sessions and thus provide information on muscle damage and adaptation to the physical load; therefore, it is necessary to measure LDH activity at baseline, 30 minutes, 6 hours, 24 hours, 48 hours, and 72 hours after the test (Brancaccio et al., 2006; Brancaccio et al., 2007; Paschalis et al., 2007). Perhaps in this study the extent of muscle damage was not high enough to result in an increase of LDH activity. In addition, other limitations of this study are unknown factors such as nutrition and physiological fluctuations of the participants (Shiran et al., 2008). Regarding the above-mentioned, LDH activity must be regularly measured in order to monitor the individual response to the plyometric training and to control all the parameters that can influence muscle damage indicators during the experimental protocol.

Previous studies of serum urea reported that elevated SU levels should be measured for two or three days to draw conclusions on changes in metabolic activity or to determine that muscle stress and damage are present (Corsetti et al., 2016; Hartmann & Mester, 2000). After a six-week plyometric training programme, Bal et al. (2012) noted no significant changes in serum urea levels among jumpers. In their study, SU levels had been measured 24 hours after the training session and showed no particular activity, except for the EGL after the first plyometric training session. Souglis et al. (2015) reported significant changes in SU levels after different sport matches, but the results decreased to baseline levels within 13 hours after the matches. It is therefore possible that, due to a higher level of physical conditioning and recovery, the SU was influenced by a better metabolic regulation and resulted in no statistical differences after 24 hours, although somewhat higher concentrations were found in each experimental group. After comparing the experimental groups, it is clear that the EGW had lower results than EGL for SU in both measurements, although there were no statistical differences, perhaps because of lower oxidative stress produced by water-based plyometrics. Considering the lower results for every muscle damage indicator, we can confirm that aquatic plyometric training has fewer effects on muscle stress and muscle damage indicators in comparison to plyometric training on land. In contrast, plyometric training on land resulted in high levels of muscle damage indicated as CK activity, as well as the metabolic stress indicator (SU), thus resulting in no adaption after the eight-week plyometric programme.

In conclusion, this study confirmed that plyometric training programmes on land and in water can affect the creatine kinase activity as an indicator of muscle damage with slightly higher levels for the group that performed the plyometric training on land and which showed significantly higher levels after eight weeks, possibly because of load adaption for the group that performed the plyometric training in water. As for the lactate dehydrogenase activity, there were no changes, while the serum urea showed that plyometric training on land can influence muscle stress and metabolic status. We can conclude that the aquatic plyometric training programme resulted in less muscle damage and can, therefore, provide an excellent practical training option when lower muscle damage effects are specifically needed. After taking into consideration all the

aspects of this study, measuring three muscle damage indicators at the same time points to the need for individual measurement of each parameter with more measuring points, as well as to the need for individual interpretation of muscle damage indicators.

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