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THE EFFECT OF AQUATIC AND LAND PLYOMETRIC TRAINING ON THE VERTICAL JUMP AND DELAYED ONSET MUSCLE SORENESS IN BRAZILIAN SOCCER PLAYERS

original paper
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ABSTRACT
Purpose. To compare the effects of aquatic and land plyometric training on the vertical jump (VJ) and delayed onset muscle soreness (DOMS) in soccer players.
Methods. Twenty-four male soccer players aged 16–18 years (16.53 ± 0.5 years) were randomly divided into three groups: aquatic plyometric training (APT) ($n = 8$; age: 16.4 ± 0.4 years; body mass: 68.3 ± 7.54 kg; height: 179.75 ± 8.13 cm); land plyometric training (LPT) ($n = 8$; age: 16.5 ± 0.5 years; body mass: 68.2 ± 7.8 kg; height: 177.0 ± 7.4 cm); and control group ($n = 8$; age: 16.7 ± 0.6 years; body mass: 61.2 ± 6.5 kg; height: 171.43 ± 5.75 cm), not performing any jump program. An identical training program was applied for 6 weeks, totalling 944 jumps. The VJ was evaluated on a leap jump platform and the Visual Analogue Scale measured the change in DOMS perception.
Results. There was a significant increase in the VJ height in both experimental groups (LPT and APT) ($p < 0.05$). A significant reduction in DOMS perception was verified for the APT group in comparison with the LPT group ($p < 0.05$) between the first and last week of training. The foot contact time significantly decreased ($p < 0.05$) in the APT group from pre- to post-test. Significant improvements ($p < 0.05$) were observed in the flight time and jump speed from pre- to post-test in both LPT and APT groups.
Conclusions. APT can increase the VJ height and reduce DOMS perception in soccer players.
Key words: land plyometric training, muscular pain perception, vertical jump, aquatic plyometric training, soccer

INTRODUCTION

A soccer match is characterized by intermittent high-intensity efforts with brief recovery periods [1]. During a soccer game, the prevalence of sprints, jumps, tackles, and dual plays is high [2]. The neuromuscular performance [3], the anaerobic metabolism, and, specifically, the anaerobic power of the lower extremities have been pointed out as crucial factors for the match outcome [4].

Plyometric training (PT) has a positive effect on maximal-intensity exercise in soccer players [5]. One possible mechanism explaining the efficacy of plyometrics can be related with a specific muscle action called stretch shortening cycle (SSC). This sequence of intense eccentric (stretch) and concentric (shortening) contractions of a muscle produces substantial improvements in jump height owing to energy storage-recoil processes and stretch reflex activation [6].

PT in the form of vertical countermovement jumps on a solid surface is frequently used in studies as a way of provoking exercise-induced muscle damage (EIMD) in the knee extensors [7–9]. The effects of EIMD begin

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approximately 6 h after exercise, peak at 24–72 h, and subside 4–7 days after exercise [10–12]. Muscle damage is mainly induced by mechanical stress and disturbances of calcium homeostasis, and a perception of discomfort within the muscle may be developed [10].

Although most PT sessions take place on land, there is increasing interest in aquatic-based exercise. The aquatic environment provides a non-impact medium that produces little strain on muscle, bones, and connective tissue when compared with land activities [13–15].

Water reduces the effects of gravity because of the buoyancy of the body and the increased density of water compared with air [16]. Buoyancy may proffer an upward thrust acting on any partially or fully immersed object in the direction opposite to gravity [17]. Aquatic PT (APT) has been indicated to reduce the symptoms of EIMD as compared with land PT (LPT) [18].

Robinson et al. [19] and Shiran et al. [20] have compared the effects of APT and LPT on muscle damage. Both studies demonstrated that an accurately designed APT program could provide comparable training improvements with an LPT program with less delayed onset muscle soreness (DOMS). If APT produces similar enhancements of performance as LPT with the benefit of reducing muscle stress, APT might be an alternative to traditional PT for the enhancement of physical performance. Thus the efficiency of APT and LPT on drop jump ability and DOMS needs to be investigated more thoroughly [5].

Therefore, the purpose of the present study was to compare the effects of APT and LPT on the vertical jump (VJ) and DOMS in soccer players.

MATERIAL AND METHODS

Participants

The study investigated 24 male soccer athletes from the youth and junior soccer teams of a soccer club in the 1st division of the state of Rio de Janeiro, Brazil, who had competed for at least 2 years and were 16–18 years old (16.53 ± 0.5 years). All participants were still actively playing soccer during the current research. The participants were divided into 2 experimental groups and 1 control group (CG). The experimental groups performed APT (n = 8; age: 16.4 ± 0.4 years; body mass: 68.3 ± 7.54 kg; height: 179.75 ± 8.13 cm) and LPT (n = 8; age: 16.5 ± 0.5 years; body mass: 68.2 ± 7.8 kg; height: 177.0 ± 7.4 cm). The CG (n = 8; age: 16.7 ± 0.6 years; body mass: 61.2 ± 6.5 kg; height: 171.43 ± 5.75 cm) did not participate in any PT program.

The inclusion criteria required that the athletes had a competitive background, had taken part in continuous training for at least 3 months before the study, and had not suffered from a knee injury within the previous 2 years. Athletes who had had any type of knee surgery within the previous 2 years were excluded from the study.

The present study was performed in accordance with the Resolution 466/12 of the National Health Council and the Declaration of Helsinki. The Research Ethics Committee of the Castelo Branco University approved the study under the number 00182008. All participants signed an informed consent form prior to taking part in the study.

Procedures

The subjects were instructed not to perform any physical exercise within the 48 h before the tests. Each player was tested for all conditions in a single visit to the club before the beginning of training. Firstly, the same researcher (intra-class correlation coefficient > 0.90) collected the following anthropometric data of all individuals: (a) total body mass, with the use of electronic scales (model BAL-150PA, 135 Techline, Brazil; scale of 0.1 kg); (b) height, with a stadiometer (model 136 E210, Wiso, Brazil; scale of 0.01 m); and (c) distance of the superior-anterior supra iliac to the bottom of the pool, which corresponded to the immersion levels, with an anthropometric measuring tape (Cescorf Anthropometrics Equipment LTDA, Brazil; scale of 0.01 m).

In all conditions, the individuals practiced for 5 min a set of submaximal countermovement jumps, drops from a 50-cm box, and drop jumps before the VJ test to familiarize themselves with the equipment.

Experimental design

The VJ test began with a drop jump departing from a 50-cm high bench. Knees were extended at 180° and hands were fixed close to the suprailiac hip region. The drop jump consisted of jumping off a bench, when the participants accomplished a fall characterized with one foot forward, the other knee bent, and the body impelling down. Therefore, the participants executed a VJ starting from a standing position with the trunk erect [21].

The jumps were performed on an Axon contact platform with the dimensions of 60 × 70 cm. The platform allows to determine the height of a jump by timing the length of the participant's flight, and the jump height was assessed from the speed of the vertical

Table 1. Aquatic and land plyometric training protocol

Weeks	Number of days per week	Number of series per day	Interval time (min)	Total number of jumps per series	Total number of jumps per day	Total number of jumps per week
1st	2	3	2	16	48	96
2nd	2	3	2	20	60	120
3rd	2	4	2	16	64	128
4th	2	4	2	20	80	160
5th	2	5	3	20	100	200
6th	2	5	3	24	120	240
Total	12	24	–	–	–	944

take-off from the centre of gravity. In the study by Toumi et al. [21], photoelectric emitters and receptors inside the jump platform started the count of the athlete's time in the air with the moment when the athlete lost contact with the floor and the light beams reached the receptors.

The height of VJ was calculated on the basis of the following formula:

$$\text{height} = g \cdot t^2 \cdot 8^{-1}$$

where 'g' is the gravitational acceleration (9.81 m/s^2) and 't' is the time spent in the air, in seconds [22].

Plyometric training

In order to emphasize the proper execution technique in drop jump protocols, 2 preliminary familiarization sessions were undertaken before the measurements. Both APT and LPT groups trained twice a week, on non-consecutive days, during 6 weeks, applying only drop jumps. The LPT occurred on a soccer field, the same environment in which the athletes must perform, and boxes of the same dimensions were used. The participants wore shoes appropriate for jumping on land.

The APT was performed in a pool with a depth of 1 m with water temperature set at 28 ± 1°C, containing two boxes (50 cm height, separated by 1 m). In the basis of the boxes, a material was employed that allowed the settlement of the boxes in the bottom of the pool, without fluctuating or sliding. The athletes performed drop jump training using their superior limbs for support with countermovement jumps. They began on one box, jumped to the ground between the boxes, and then jumped onto the second box. The same protocol was then reversed to complete one repetition. The CG did not perform any kind of jump program during this period, undergoing just technical soccer training.

Table 1 presents the protocol of the APT and the LPT. The protocols were based on the results of 58 studies concerning PT, 8 of which involved drop jumps in the meta-analysis [23].

Delayed onset muscle soreness

The DOMS of the knee extensors was assessed in each participant through the Visual Analogue Scale [24]. The scale was numbered from 1 to 10 (on the reverse side of the sliding scale), with 1 representing no muscle soreness and 10 indicating that the muscle was very, very sore to move. With hands on hips and squatting to an approximate knee angle of 90°, the volunteers should indicate the level of perceived soreness on the rating scale. This corresponded to the location of the perceived muscle soreness on the continuum. The technique has been used successfully in previous studies [11, 25, 26]. The reliability coefficient for a repetitive measurement in DOMS was 0.98 [24].

Statistical analysis

The data were analysed with the use of the IBM SPSS Statistics 20 for Windows and presented as a mean and standard deviation. The Shapiro-Wilk and Levene's tests were applied to verify the normality and variance homogeneity of the data, respectively. The ANOVA with repeated measures was employed in groups' factors (APT, LPT, and CG) and time (pre- and post-test), followed by the Bonferroni post-hoc test to identify possible differences. In addition, the size effect (*d*) was calculated to analyse the results magnitude of the present study. The study adopted $p < 0.05$ as the significance level.

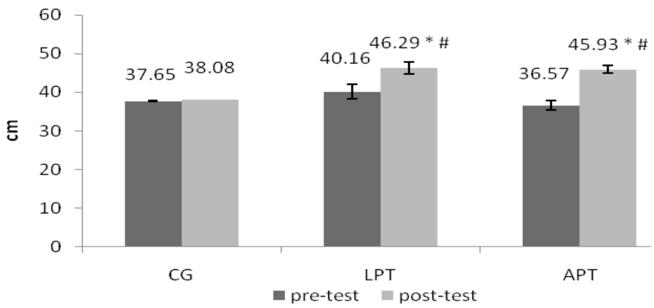
Ethical approval

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

RESULTS

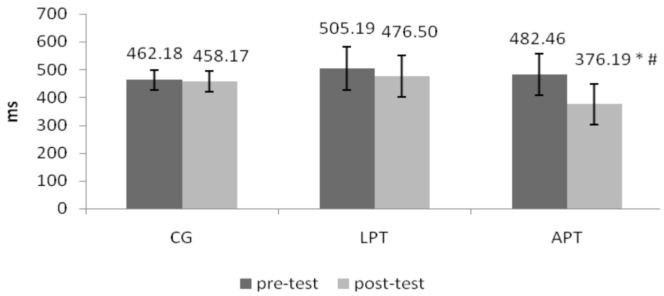
The sample of the study presented a distribution close to the normal curve and the groups were similar at the beginning of the research in all variables analysed. The ANOVA with repeated measures showed an interaction between groups and the moments before and after the intervention (Wilk's lambda = 0.384; F = 8.539; $p < 0.001$).

Figure 1 shows the analysis of the VJ height among the studied groups. The VJ height significantly increased ($p < 0.05$) from pre- to post-test in both experimental groups (LPT and APT). In the inter-group comparisons, a significant increase was observed ($p < 0.05$) in the VJ height in LPT and APT groups when compared with CG in the post-test. The effect size in the APT ($d_{APT} = 5.37 > 0.82$) and LPT ($d_{LPT} = 3.48 > 0.82$) was strong for the VJ and indicated an improvement in results in a substantial number of participants. In the CG, the effect size was poor ($d_{CG} = 0.21 < 0.30$).



CG – control group
LPT – land plyometric training
APT – aquatic plyometric training
* $p < 0.05$ pre-test vs. post-test,
# APT post-test and LPT post-test vs. CG post-test

Figure 1. Analysis of vertical jump height



CG – control group
LPT – land plyometric training
APT – aquatic plyometric training
* $p < 0.05$ pre-test vs. post-test
# APT post-test vs. LPT post-test and CG post-test

Figure 2. Analysis of foot contact time

Figure 2 presents the analysis of the foot contact time on the ground among the groups. The foot contact time significantly decreased ($p < 0.05$) from pre- to post-test in the APT group. In the inter-group comparisons, a significant decrease was observed ($p < 0.05$) in the foot contact time in APT group when compared with LPT group and CG in the post-test. The effect size in the APT ($d_{APT} = 3.40 > 0.82$) and LPT ($d_{LPT} = 1.26 > 0.82$) was strong for the foot contact time and indicated an improvement in results in a substantial number of participants. In the CG, the effect size was poor ($d_{CG} = 0.22 < 0.30$).

Table 2 presents intra- and inter-group comparisons in the flight time and jump speed variables. Significant improvements ($p < 0.05$) were observed in the flight time and jump speed from pre- to post-test in

Table 2. Analysis of the flight time and jump speed in the sample

Variable	Group	Mean ± *SD* (pre-test)	Mean ± *SD* (post-test)
Flight time (m/s)	CG	552.17 ± 6.86	555.67 ± 6.81
	LPT	561.75 ± 8.92	595.54 ± 9.41*
	APT	544.44 ± 15.33	623.89 ± 15.62*#
Jump speed (m/s)	CG	2.72 ± 0.03	2.75 ± 0.04
	LPT	2.61 ± 0.04	2.99 ± 0.05*
	APT	2.47 ± 0.22	3.21 ± 0.19*#

CG – control group
LPT – land plyometric training
APT – aquatic plyometric training
* $p < 0.05$ pre-test vs. post-test
# APT post-test vs. CG post-test

Table 3. Analysis of muscle soreness perception in LPT and APT groups

Group	Mean ± *SD* (pre-test)	Mean ± *SD* (post-test)
LPT	1.83 ± 0.56	1.50 ± 0.50
APT	1.61 ± 1.02	0.19 ± 0.21*#

LPT – land plyometric training
APT – aquatic plyometric training
* $p < 0.05$ pre-test vs. post-test
# APT post-test vs. LPT post-test

both experimental groups (LPT and APT). In the inter-group comparisons, there was a significant increase ($p < 0.05$) in flight time and jump velocity in APT when compared with CG in the post-test. The effect size was stronger in the APT group than in the LPT group ($d_{APT} > d_{LPT} > 0.80$) for the variables of flight time and jump speed.

The responses of the groups concerning muscle soreness perception were compared between the first and last week of training. A significant reduction in DOMS was found in the post-test results ($p < 0.001$) of the APT group when compared with the LPT group. The effect size was strong in the APT ($d_{APT} > 0.80$) and moderate in the LPT group ($d_{LPT} < 0.80$). This indicates an improvement in results (Table 3).

DISCUSSION

The results of the present study showed significant differences in the VJ in the intervention groups (APT and LPT) when compared with CG. Söhnlein et al. [27] obtained similar results. They found significant improvements ($p < 0.05$) in the performance of the standing long jump (+ 7.3%), which requires greater muscular power of the quadriceps, similar to what happens in VJ. The elite soccer players ($n = 18$; age: 13.0 ± 0.8 years) also presented an increase in performance in the 20-m sprint time (23.2%; $p < 0.05$), agility time (26.1%; $p < 0.05$), multiple 5 bounds (+ 11.8%; $p < 0.05$) related to speed after 16 weeks of PT, with 2 sessions per week.

A study by Miller et al. [28] also demonstrated, after 6 weeks of PT, significant changes, increasing the VJ height, strength, and muscular power answers. According to Campillo et al. [29], the LPT appears to contribute to the performance in the VJ and in kicking in soccer players. Thus, incorporating plyometrics into the VJ can produce significantly different results regarding this motor ability [30].

Martel et al. [31], after 4 weeks of training, observed that increases in VJ were similar in APT and LPT groups. However, between weeks 4 and 6, the APT group enhanced an additional 8%, whereas the control group showed no further increases. Concentric peak torque during knee extension and flexion improved significantly after 6 weeks in both groups. The results concerning the increase of VJ noted in the APT and LPT groups when compared with CG in the studies by Miller et al. [28] and Martel et al. [31] are similar to those for the VJ in both groups in the present study. The training period (6 weeks) of the present study was the same as applied by both mentioned authors.

Lavanant et al. [18] reported a significant increase in muscle power in the group undergoing aquatic training. Fabricius [17] observed that the group that trained in the land obtained significant development in the tests of speed, agility, and power of lower limbs. However, the aquatic training group showed significant improvement in VJ height and horizontal jump distance. These investigations corroborate the results of the present study in which the inter-group comparisons presented a significant increase ($p < 0.05$) in the VJ height in APT and LPT groups when compared with CG in the post-test. The significant increase proved in the APT group ($p < 0.05$) in intra-group vertical impulsion and in comparison with the CG group probably occurred owing to the resistance offered by the water during the concentric phase of the VJ, which may have contributed to an increase in the muscular power of the quadriceps among these soccer players.

Increased resistance to movement through the water (drag) involves additional muscle activation to overcome the resistance and produce the same movement that is more easily generated in the air [32]. Aquatic exercise provides strength gains through the increased energy needs of the body working in an aquatic environment [33]. According to Louder et al. [34], additionally, acute investigations into kinetic differences between land- and aquatic-based movement suggest potential clinical and performance benefits for movements performed in the water.

Decreased amounts of force applied (load) experienced during landing in APT, facilitating a faster transition from eccentric to concentric activity may occur [17]. Fabricius [17] reported that LPT caused heavier loads (no buoyancy effect) at lower velocities and a longer amortization phase, improving strength but not power. In the study by Colado et al. [16], buoyancy of water reduced the weight, stretch reflex, and amount of eccentric loading experienced during APT, facilitating the concentric muscular component of a plyometric jump, and theoretically shortening the amortization phase of a plyometric task.

In the present study, the foot contact time significantly decreased ($p < 0.05$) from pre- to post-test in the APT group. In the inter-group comparisons, a significant decrease ($p < 0.05$) was also observed in the foot contact time in APT group when compared with LPT group and CG in the post-test. This reduction in post-training contact time in the APT group found in the present study probably decreased the impact force on the soil in the group. Triplett et al. [13] reported that the landing impact force decreased by 44.8% when jumping in water. The total jump time was shorter ($p < 0.05$) for the aquatic jumps, whereas the time required to reach peak concentric force was not significantly different from the land jumps, despite the greater resistance to movement in the aquatic environment.

In another study [17], APT improved leg power, which can be explained by the use of buoyancy and fluid resistance. Buoyancy reduces the total body mass of the participant, for faster total jump time and theoretically reduced ground contact time. The fluid resistance produces a greater concentric contraction of the SSC. In the present study, significant improvements ($p < 0.05$) were observed in the flight time and jump speed from pre- to post-test in both experimental groups (LPT and APT). In the inter-group comparisons, there was a significant increase ($p < 0.05$) in flight time and jump velocity in APT when compared with CG in the post-test, which can be explained by the use of buoyancy and fluid resistance that probably could raise the leg power of the soccer players in favour of the APT group.

The magnitude of the buoyant force is always equal to the weight of the fluid displaced by the immersed object [35]. Buoyancy has a direct influence upon an object immersed in water, decreasing the effects of gravity [36]. According to Triplett et al. [13] and Donoghue et al. [14], this could be estimated for the properties of water, specifically, where the buoyancy provided owing to fluid density compared with air density reduces significantly (by 33–54%; $p < 0.05$) the ground reaction forces (GRF) in water compared with land for all exercises. This was consistent with previous research [13, 14] that found reductions of 45% and 59% in peak GRF during single- and double-leg squat jumps in aquatic environment at the level of the xiphoid process.

The reduction in contact time noted in favour of the APT group ($p < 0.05$) in the present study probably decreased the impact force on the soccer players, even with a lower depth of water, when compared with that used in the studies previously mentioned [13, 14]. According to Miller et al. [37], some studies have shown that both shallow-water and deep-water training have benefits depending on the type and purpose of training. In the present study, the water surface was at the level of the iliac crest of the participants. This depth seemed to be sufficient, since it presented a significant reduction ($p < 0.05$) in the DOMS reports when compared with the LPT group. It suggests a decrease in the impact on the APT group, since the high vertical GRFs have been identified as the main causes of soccer injury, owing to the stress that they exert on the musculoskeletal system [2].

Among the effects of PT in the aquatic environment, it is important to highlight the results of landing phases of the drop jump and the subjective perception of DOMS, since this type of training generates a great eccentric load. Increasing immersion leads to a decrease in the landing phase ($p < 0.001$), with the decrease in peak forces between immersions being greater with deeper immersion levels [35]. In the present study, the immersion level of 1-m depth seems to have been efficient because of the significant reduction ($p < 0.05$) in the DOMS responses observed in the APT group when compared with the LPT group.

Aquatic training becomes an important training strategy as it allows recreational athletes to maintain their performance in the VJ with the decrease of DOMS [38]. In the present study, the APT group obtained a significant increase in vertical impulsion ($p < 0.05$), similar to LPT group and higher than CG, but with a significant reduction in DOMS in the post-test results ($p < 0.05$) when compared with the LPT.

The results obtained in the studies by Triplett et al. [13], Donoghue et al. [14], Colado et al. [16], Lavanant et al. [18], and Robinson et al. [19] with jumps performed directly on the ground presented higher subjective perception of DOMS after 48 and 96 h of training sessions because of the increase in the training load. These results differ from the findings of Miller et al. [28] and the present study, which indicated significantly higher subjective perception of DOMS ($p < 0.05$) in the group that performed jumps on the land as compared with the group of jumps performed in the water and with the CG after 6 weeks of training.

The significant reduction of the DOMS ($p < 0.05$), found in the APT group compared with the LPT group in the present study, may have occurred owing to the reduction of impact in the aquatic training. This was also observed in the study by Fabricius [17], presenting significantly reduced (by 33–54%) GRF in water for all exercises ($p < 0.05$). This was consistent with previous research that proved reductions of 45% and 59% in peak GRF during single- and double-leg squat jumps in water at the level of the xiphoid process [13, 16].

Nielson [39] showed significant reductions in the impact force that could be attributed to the buoyancy force experienced by the body. This lower rate of force development (RFD) impact suggests reductions in the stress to the musculoskeletal system [40]. In another study, the impact force and impact force development rate were two parameters that indirectly indicated the stress level that the musculoskeletal system receives

[41]. Therefore, aquatic jumps could generate less joint stress because impact force RFD can be 80% slower in water than on dry land [13].

The peak responses of the reaction force against the land observed in several studies [2, 13, 14, 16, 35] indicated a reduction in DOMS responses and some muscle injury markers in the groups of jumps performed in water when compared with those performed directly on the land. The present study did not evaluate the peak of the reaction force against the land. This could be considered as its limitation, since the information could contribute to the comparative analyses of APT and LPT.

CONCLUSIONS

The PT program employed in the present study proved to be efficient, as it provided a significant increase of VJ in both training groups (APT and LPT). However, the APT group achieved a reduction in the time of contact with the land and the responses of the DOMS when compared with the results obtained in the LPT group.

Aquatic environment may constitute an alternative to be used by soccer athletes and physically active individuals at different stages of training, with the objective of increasing the performance of vertical impulsion, with reduction of the impact and the DOMS. These conditions can prevent injuries resulting from PT.

It is recommended that studies investigate the effects of PT on creatine kinase, the peak of the reaction force against the land, the specific location of pain, and the intensity of possible inflammatory conditions of the involved muscles aroused by training. These variables may contribute to the prevention of muscular injuries.

Disclosure statement

Disclosure statement: No author has any financial interest or received any financial benefit from this research.

Conflict of interest

Authors state no conflict of interest.

References

1. Di Mascio M, Bradley PS. Evaluation of the most intense high-intensity running period in English FA premier league soccer matches. J Strength Cond Res. 2013;27(4): 909–915; doi: 10.1519/JSC.0b013e31825ff099.
2. Yanci J, Camara J. Bilateral and unilateral vertical ground reaction forces and leg asymmetries in soccer players. Biol Sport. 2016;33(2):179–183; doi: 10.5604/20831862.1198638.
3. Haugen TA, Tønnessen E, Seiler S. Anaerobic performance testing of professional soccer players 1995–2010. Int J Sports Physiol Perform. 2013;8(2):148–156; doi: 10.1123/ijspp.8.2.148.
4. Stølen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. Sports Med. 2005;35(6):501–536; doi: 10.2165/00007256-200535060-00004.
5. Campillo RR, Pedreros MV, Olguín CH, Salazar CM, Alvarez C, Nakamura FY, et al. Effects of plyometric training on maximal-intensity exercise and endurance in male and female soccer players. J Sports Sci. 2015;34(8): 687–693; doi: 10.1080/02640414.2015.1068439.
6. Makaruk H, Czaplicki A, Sacewicz T, Sadowski J. The effects of single versus repeated plyometrics on landing biomechanics and jump performance in men. Biol Sport.2014;31(1):9–14;doi:10.5604/20831862.1083273.
7. Macaluso F, Isaacs AW, Di Felice V, Myburgh KH. Acute change of titin at mid-sarcomere remains despite 8 wk of plyometric training. J Appl Physiol. 2014;116(11): 1512–1519; doi: 10.1152/japplphysiol.00420.2013.
8. Major BP. Moderate intensity cycling following eccentric contractions does not attenuate indirect markers of muscle damage. Electronic Thesis and Dissertation Repository; 2013.
9. Jakeman JR, Byrne C, Eston RG. Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. Eur J Appl Physiol. 2010;109(6):1137–1144; doi: 10.1007/s00421-010-1464-0.
10. Chatzinikolaou A, Fatouros IG, Gourgoulis V, Avloniti A, Jamurtas AZ, Nikolaidis MG, et al. Time course of changes in performance and inflammatory responses after acute plyometric exercise. J Strength Cond Res. 2010; 24(5):1389–1398; doi: 10.1519/JSC.0b013e3181d1d318.
11. McFarlin BK, Venable AS, Henning AL, Sampson JNB, Pennel K, Vingren JL, et al. Reduced inflammatory and muscle damage biomarkers following oral supplementation with bioavailable curcumin. BBA Clin. 2016;5:72–78; doi: 10.1016/j.bbacli.2016.02.003.
12. Nicol LM, Rowlands DS, Fazakerly R, Kellett J. Curcumin supplementation likely attenuates delayed onset muscle soreness (DOMS). Eur J Appl Physiol. 2015; 115(8):1769–1777; doi: 10.1007/s00421-015-3152-6.
13. Triplett NT, Colado JC, Benavent J, Alakhdar Y, Madera J, Gonzalez LM, et al. Concentric and impact forces of single-leg jumps in an aquatic environment versus on land. Med Sci Sports Exerc. 2009;41(9):1790–1796; doi: 10.1249/MSS.0b013e3181a252b7.
14. Donoghue OA, Shimojo H, Takagi H. Impact forces of plyometric exercises performed on land and in water. Sports Health. 2011;3(3):303–309; doi: 10.1177/1941738111403872.
15. Torres-Ronda L, Del Alcázar XS. The properties of water and their applications for training. J Hum Kinet. 2014;44(1):237–248; doi: 10.2478/hukin-2014-0129.
16. Colado JC, Garcia-Masso X, González LM, Triplett NT, Mayo C, Merce J. Two-leg squat jumps in water:

an effective alternative to dry land jumps. Int J Sports Med. 2010;31(2):118–122; doi: 10.1055/s-0029-1242814.
17. Fabricius DL. Comparison of aquatic- and land-based plyometric training on power, speed and agility in adolescent rugby union players. Thesis, Stellenbosch University; 2011. Available from: http://hdl.handle.net/10019.1/17811.
18. Lavanant AJ, Cruz JRA, Blanco FP, Romero CM, Rosell DR, Garcia JCF. The effects of aquatic plyometric training on repeated jumps, drop jumps and muscle damage. Int J Sports Med. 2015 [Epub ahead of print]; doi: 10.1055/s-0034-1398574.
19. Robinson LE, Devor ST, Merrick MA, Buckworth J. The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. J Strength Cond Res. 2004;18(1):84–91; doi: 10.1519/00124278-200402000-00012.
20. Shiran MY, Kordi MR, Ziaee V, Ravasi A, Mansournia MA. The effect of aquatic and land plyometric training on physical performance and muscular enzymes in male wrestlers. Res J Biol Sci. 2008;3(5):457–461.
21. Toumi H, Best TM, Martin A, F'Guyer S, Poumarat G. Effects of eccentric phase velocity of plyometric training on the vertical jump. Int J Sports Med. 2004;25(5):391–398; doi: 10.1055/s-2004-815843.
22. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377–381; doi: 10.1249/00005768-198205000-00012.
23. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med. 2007;41(6):349–355; doi: 10.1136/bjsm.2007.035113.
24. Arazi H, Eston R, Asadi A, Roozbeh B, Zarei AS. Type of ground surface during plyometric training affects the severity of exercise-induced muscle damage. Sports. 2016;4(1):15; doi: 10.3390/sports4010015.
25. Twist C, Eston RG. The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. Eur J Appl Physiol. 2005;94(5–6):652–658; doi: 10.1007/s00421-005-1357-9.
26. Impellizzeri FM, Rampinini E, Castagna C, Martino F, Fiorini S, Wisloff U. Effect of plyometric training on sand versus grass on muscle soreness, jumping and sprinting ability in soccer players. Br J Sports Med. 2008;42(1):42–46; doi: 10.1136/bjsm.2007.038497.
27. Söhnlein Q, Müller E, Stöggl TL. The effect of 16-week plyometric training on explosive actions in early to mid-puberty elite soccer players. J Strength Cond Res. 2014;28(8):2105–2114; doi: 10.1519/JSC.0000000000000387.
28. Miller M, Ploeg AH, Dibbet TJ, Holcomb WR, Berry, DC, O'Donoghue J. The effects of high volume aquatic plyometric training on vertical jump, muscle power, and torque. J Strength Cond Res. 2010;24(1):1; doi: 10.1097/01.JSC.0000367176.63902.62.
29. Campillo RR, Meylan C, Alvarez C, Olguín CH, Martinez C, Jamett RC, et al. Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. J Strength Cond Res. 2014;28(5):1335–1342; doi: 10.1519/JSC.0000000000000284.
30. Stojanović E, Ristić V, McMaster DT, Milanović Z. Effect of plyometric training on vertical jump performance in female athletes: a systematic review and meta-analysis. Sports Med. 2017;47(5):975–986; doi: 10.1007/s40279-016-0634-6.
31. Martel GF, Harmer ML, Logan JM, Parker CB. Aquatic plyometric training increases vertical jump in female volleyball players. Med Sci Sports Exerc. 2005;37(10):1814–1819; doi: 10.1249/01.mss.0000184289.87574.60.
32. Jurado-Lavanant A, Fernandez-García JC, Alvero-Cruz JR. Aquatic plyometric training [in French]. Sci Sports. 2013;28(2):88–93; doi: 10.1016/j.scispo.2012.08.004.
33. Wang YC, Zhang N. Effects of plyometric training on soccer players. Exp Ther Med. 2016;12(2):550–554; doi: 10.3892/etm.2016.3419.
34. Louder TJ, Searle CJ, Bressel E. Mechanical parameters and flight phase characteristics in aquatic plyometric jumping. Sports Biomech. 2016;15(3):342–356; doi: 10.1080/14763141.2016.1162840.
35. Haupenthal A, Ruschel C, Hubert M, Fontana HB, Roesler H. Loading forces in shallow water running at two levels of immersion. J Rehabil Med. 2010;42(7):664–669; doi: 10.2340/16501977-0587.
36. Wertheimer V, Jukic I. Aquatic training: an alternative or a complement to the land-based training. Hrvat Šports Vjesn. 2014;28(2):57–66.
37. Miller MG, Cheatham CC, Porter AR, Ricard MD, Hennigar D, Berry DC. Chest- and waist-deep aquatic plyometric training and average force, power, and vertical-jump performance. Int J Aquat Res Educ. 2007;1(2):145–155; doi: 10.1201/9781420058987.ch9.
38. Dell'Antonio E, Ruschel C, Haupenthal A, Roesler H. Aquatic plyometric training: applicability for sport performance [in Portuguese]. Rev Bras Ciênc Mov. 2016;24(4):213–219.
39. Nielson SL. Comparison of land and aquatic loaded countermovement jump landings in female NCAA Division I collegiate athletes. Logan: Utah State University; 2017.
40. Louder T, Bressel E, Baldwin M, Dolny DG, Gordin R, Miller A. Effect of aquatic immersion on static balance. Int J Aquat Res Educ. 2014;8(1):53–65; doi: 10.1123/ijare.2013-0014.
41. Irmischer BS, Harris C, Pfeiffer RP, DeBeliso MA, Adams KJ, Shea KG. Effects of a knee ligament injury prevention exercise program on impact forces in women. J Strength Cond Res. 2004;18(4):703–707; doi: 10.1519/R-13473.1.