EFFECTS OF SIX WEEKS OF DEPTH JUMP VS. COUNTERMOVEMENT JUMP TRAINING ON SAND ON MUSCLE SORENESS AND PERFORMANCE

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Abstract:

The purpose of this study was to examine the effects of six weeks of depth jump (DJ) vs. countermovement jump (CMJ) training on sand on muscle soreness, jump, sprint, agility and leg press strength. Thirty healthy men (age 20.4±1.1 years; height 177.4±5.1 cm; mass 72.8±9.7 kg) volunteered to participate and were randomly assigned to one of three groups: DJ training group (n=10), CMJ training group (n=10) or control group (n=10). The experimental groups performed either DJ or CMJ training two days a week for six weeks. The training program included five sets of 20 repetitions DJ (from the height of a 45-cm box) or CMJ exercise onto 20 cm of dry sand. Assessments of Vertical Jump Test (VJT), Standing Long Jump Test (SLJT), 20 and 40 m sprints, T-Test (TT), Illinois Agility Test (IAT), and one-repetition maximum Leg Press ($1RM_{LP}$) were performed a week before and following the 6-week training period. Muscle soreness was also measured pre, immediately post, 24 and 48 hours after the first and last training sessions. Significant increases were observed in both the DJ and CMJ groups in VJT (16.2 vs. 13.5%), and SLJT (13.9 vs. 14.4%) ($p<.05$). Significant decreases in 20 and 40 m sprint times, TT and IAT were observed in both groups (20 m: 8.5 vs. 7.4%; 40 m: 6.1 vs. 3.8%; TT: 9.3 vs. 12%; IAT: 9.2 vs. 10.6% in DJ and CMJ groups, respectively). Only the CMJ group made significant improvements in $1RM_{LP}$ ($p<.05$). The CMJ group had significantly greater perception of muscle soreness than the DJ and CG groups in the rectus femoris at 48 hours post the first training session ($p<.05$). No significant differences were observed among groups in muscle soreness after the last training session ($p>.05$). These observations may have considerable practical relevance for the optimal design of plyometric training programs, given that DJ and CMJ training on sand is effective for improving muscular performance.

Key words: *depth jump, countermovement jump, stretch-shortening cycle, muscle damage*

Introduction

Plyometric training gained popularity in the early 1970s as athletes from Eastern European countries began to dominate power-dependent events (Chu, 1998). Plyometric training is widely used to improve the ability of skeletal muscles to generate power. The method involves a repeated series of bouts, each comprising a rapid deceleration of the body, followed immediately by a brief transition phase and rapid acceleration in the opposite direction. This rapid combination of eccentric and concentric muscular activity involves the stretch-shortening cycle (SSC), which provides a physiological advantage in that the muscular force developed during the concentric phase is potentiated by the preceding eccentric action (Tofas, et al., 2008; Chatzinikolaou, et al., 2010).

The specific effects of plyometrics on performance in different types of vertical jumps could be of importance in various sporting activities (Saez de Villarreal, Kells, Kraemer, & Izquierdo, 2009). It has been suggested that plyometric training is more effective in jump performance because it enhances the ability of subjects to use the elastic and neural benefits of SSC (Gehri, Ricard, Kleiner, & Kirkendall, 1998; Saez de Villarreal, et al., 2009; Thomas, French, & Philip, 2009). Keeping the specificity of contraction-type training in mind (i.e. SSC muscle function), greater positive effects of plyometric training on depth jumps (DJ) and countermovement jumps (CMJ) than on other jumps can be expected (Gehri, et al., 1998; Saez de Villarreal, et al., 2009; Thomas, et al., 2009). DJ and CMJ have differences in SSC (fast vs. slow) and ground contact time (<200-300 milliseconds vs. >400 milliseconds), but both have been shown to improve vertical jump (VJ), agility, sprint and strength (Gehri, et al., 1998; Saez de Villarreal, et al., 2009; Saez de Villarreal, Reguena, & Newton, 2010; Saez de Villarreal, Reguena, & Cronin, 2012; Thomas, et al., 2009; Markovic & Mikulic, 2010), whereas no significant differences in sprint, agility and VJ between DJ and CMJ over 12-week or 6-week training periods has been reported (Gehri, et al., 1998; Thomas, et al., 2009).

A number of studies have reported that plyometric training alone is able to induce muscular performance benefits in lower limb muscles that also contribute to power development and represents a significant advantage of this type of training (Rimmer & Sleveret, 2000; Markovic, Jukic, Milanovic, & Metikos, 2007; Asadi & Arazi, 2012; Arazi, Coetzee, & Asadi, 2012; Asadi, 2013). Very recently, Michailidis et al. (2013) reported that plyometric training is able to induce positive adaptations in performance of pre-adolescent soccer players in only six weeks of training.

An important consideration regarding the influence of plyometric training on muscle performance is the nature of the training surface. Implementation of plyometric training in an aquatic setting has been observed to induce less soreness than plyometric training on a firm surface, but with the same improvements in muscular performance (Robinson, Décor, Merrick, & Buckworth, 2004; Arazi & Asadi, 2011; Arazi, et al., 2012). Robinson and coworkers (2004) attributed the lower soreness in the aquatic versus the land plyometric group to the lower strain on the musculoskeletal system. Similarly, as a sand surface is associated with a greater degree of shock absorbance and lower stress to soft tissue and bones on the lower limbs (Barrett, Neal, Roberts, 1997), less muscle soreness is observed after similar plyometric activity on a sand surface compared to a firm, wooden surface (Miyama & Nosaka, 2004). In addition, Impellizzeri et al. (2008) reported similar improvements in jumping and sprinting ability following four weeks of plyometric training on sand and grass surfaces.

Plyometric training on a sand surface can play a role in shock absorption and reduce stress on bones and tissues (Bishop, 2003). However, the friction and instability of sand can induce negative effects on SSC, decreases in the myotatic reflex, degradation of elastic energy potentiation and an increase in the amortization phase resulting in performance decrements (Giatsis, Kollias, Panoutsakopoulos, & Papaiakovou, 2004; Impellizzeri, et al., 2008). Although a number of studies have explored the effects of DJ vs. CMJ executed on land surface, to our knowledge there is no information concerning the effectiveness or comparison of DJ vs. CMJ performed on sand. In this regard, it would be interesting to examine the adaptability of DJ vs. CMJ training on a sand surface, as some studies in the literature determined that sand can be one of the best surfaces for performing plyometrics and reported less muscle soreness compared to a land and/or grass group (Miyama & Nosaka, 2004; Impellizzeri, et al., 2008).

Therefore, the main purpose of this study was to investigate the influence of six weeks of plyometric training (DJ vs. CMJ) executed on sand on jumping ability and agility, strength and sprinting performance. It was hypothesized that CMJ training on sand would elicit greater changes in muscular strength over DJ training on sand and that DJ training on sand would also increase power and agility over CMJ training on sand with regard to controlling training intensity (height of jump).

Methods

Study design

This study was designed to address the question of how two different types of plyometric training (DJ vs. CMJ) on sand affect jumping ability and sprint, strength and agility gains, after a 6-week training program. To do this, we compared the effects of six weeks of plyometric training in three groups of subjects with a different type of plyometric training program. Muscle strength, jumping ability, sprinting and agility performance tests were performed before and after training. Muscle soreness was also measured pre, immediately post, 24 and 48 hours after the first and last training session. This design enabled us to examine the impact of sand surface on muscular performance. The initial tests were completed on two days as part of a regular testing program. After the initial measurements, subjects were randomly assigned to one of three groups: control (n=10), DJ (n=10) or CMJ (n=10). The control group did not train. Before the initiation of the training program subjects in all groups were instructed about the proper execution of all the exercises that were to be done during the training period. The training protocols only included DJ or CMJ. None of the subjects had performed plyometric exercises before. All training sessions were supervised. All subjects in the experimental groups performed plyometric exercises at 02:00 p.m. They were instructed to avoid any strenuous physical activity during the experiment and to maintain their dietary habits for the whole duration of the study.

Participants

Thirty untrained healthy men volunteered to participate in the study. None of the subjects had any background in regular strength training or competitive sports that involved any kind of jumping exercise six months before their inclusion in the study. After the baseline testing, the subjects were randomly assigned to one of the three groups: depth jump training group (DJ; n=10; age 20.7±0.8 years; height 180.4±6.6 cm; mass 75.2±8.9 kg), coun-termovement jump training group (CMJ; n=10; age 21.2±1.2 years; height 176.7±4 cm; mass 70.8±8.3 kg) or control group (CG; n=10; age 19.5±0.4 years; height 175.2±3.1 cm; mass 72.5±12.1 kg) (M±SD). The control group did not train but were tested before and after a 6-week period. All sub-jects were asked to complete a personal health and medical history questionnaire, which served as a screening tool. All subjects had no history of any kind of medical condition that would prevent them from participating in the training intervention. The University's ethics committee approved the experimental procedures and study protocols, which were fully explained to all subjects. Each subject signed a written consent form after having read and understood the details of the experiment. A prior estimated sample size (n=10 for each group) for β=.80 with α=.05 was calculated based on tabled data from previous research (Markovic, 2007). Inclusion criteria was the ability of an individual to lift a weight more than 2.5 times the body weight in a leg press exercise. Exclusion criteria were applied to potential subjects with potential medical problems or a history of ankle, knee, or back pathology in the three months preceding the study; subjects with medical or orthopedic problems that compromised their participation or performance in this study or any lower extremity reconstructive surgery in the past two years or unresolved musculoskeletal disorders; and subjects who were taking and had previously taken anabolic steroids, growth hormone, or related performance-enhancing drugs of any kind.

Testing procedure

Height was measured using a wall-mounted stadiometer (Seca 222, Terre Haute, IN) recorded to the nearest cm. Body mass was measured to the nearest 0.1 kg using a medical scale (Tanita, BC-418MA, Tokyo, Japan). The subjects were carefully familiarized with the test procedure of voluntary force and power production during several sub-maximal and maximal actions a few days before the measurements were taken, and the tests were also done previously for training control purposes. The subjects also completed several explosive-type actions to become familiar with the action required to move different loads rapidly and with the jump technique. In addition, several warm-up activities (10-minute warm-up protocol consisting of sub-maximal running, active stretching and jump exercises) were performed prior to the actual maximal and explosive tests. All tests were carried out before and after six weeks of plyometric training. The subjects were tested at the exact same time of day (pre- and post-test) to minimize the effect of circadian variations in the test results. The performance tests were completed in two days. On day one, the following tests were completed: measurement of body height, body mass; Vertical Jump Test; Standing Long Jump Test; 20 and 40-m sprint. On day two, T-Test, Illinois Agility Test and $1RM_{LP}$ were completed. All subjects were instructed to continue with their normal physical activity (not related to the study) through the duration of the study. Subjects had not participated in any type of plyometric training program for at least six months prior to the start of the study and were not permitted to participate in any resistance training or SSC training during the time period of the study. A certified strength and conditioning specialist conducted the tests. Additionally, care was taken to allow sufficient rest between all tests to limit the effects of fatigue in subsequent tests.

To determine reliability, two measurements were made in 10 subjects, 48 hours apart.

Perceived muscle soreness

Muscle soreness was assessed pre, immediately post, 24 and 48 hours after the first and last training session. Each subject determined the soreness of their rectus femoris, biceps femoris, and gastrocnemius muscles using a visual analogue scale. The scale was numbered from 1 to 10 with 1 indicating no muscle soreness and 10 meaning that the muscles were too sore to move. With their hands on hips and squatting to an approximate knee angle of 90°, participants were asked to indicate the level of perceived soreness based upon the rating scale. This technique has been used successfully in previous studies (Chatzinikolaou, et al., 2010). The reliability coefficient (ICC) for muscle soreness was .97.

Jump performance

Jump performance was used in order to maximize SSC activity and to assess explosive strength of the lower extremity muscles. Jump performance was assessed using the Vertical Jump Test (VJT) and Standing Long Jump Test (SLJT). The VJT was assessed using a Vertec (Power System, Knoxville, Tennessee). Jump height was determined using an acknowledged Vertec technique calculation (Robinson, et al., 2004). During the jump, the subjects were instructed to use their hands while performing a downward movement followed by a maximal-effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees following landing. For the SLJT, the subjects were required to stand with their toes behind the zero point of the tape measure prior to jumping. Each subject initiated the jump with countermovement and arm swing. Each subject jumped horizontally as far as possible and landed over the top of a tape measure secured to the floor. Distance was determined measuring the point at which the heel of the trial leg touched the ground. Each subject was given three trials, and the highest score was recorded for analysis. A 30-second break between trials was allowed for rest (Markovic, et al., 2007). ICCs for the VJT and SLJT were .95 and .99, respectively.

Sprint

The sprint running tests were performed on an indoor track. The test consisted of two maximal sprints of 40 meters, with a 180-second rest period between each sprint. Running time was recorded using a stopwatch (Joerex, ST4610-2, China) at the end of the 20-and 40-m sprints, with an accuracy of 0.01s. Each subject was given two practice trials performed at half speed after a thorough warm-up along the running track. When ready, the subjects commenced the sprint from a standing start, behind the start line. On the "Go" command, each subject ran 40 meters as quickly as possible and their time was recorded for 20- and 40-meter distances. The fastest time for each distance was used for analysis (Rimmer & Sleveret, 2000). ICCs for the 20- and 40-m sprints were .94 and .97, respectively.

Agility

Agility was assessed using the T-Test (TT) and Illinois Agility Test (IAT). The tests were conducted on a wooden basketball court. Agility time was recorded using a stopwatch (Joerex, ST4610-2, China). The TT was used to determine speed with directional changes such as forward sprinting, left and right side shuffling, and backpedaling (Arazi, et al., 2012). The subjects were instructed to sprint from a standing starting position to a cone 10 meters away, followed by a side-shuffle left to a cone 5 meters away. After touching the cone, the subjects side-shuffled to the cone 10 meters to the right and then side-shuffled back to the middle cone. The test was concluded by back-pedaling to the starting line. The test score was recorded as the best time of two trials. Subjects were disqualified if they failed to touch the base of any cone, crossed one foot in front of the other or failed to face forward for the entire test. The IAT was used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles. The run started from a standing start on the command "Go" and the subjects sprinted 10 meters, turned, and returned to the starting line. When the subjects reached the starting line, they zig-zagged in between four markers and completed two 10-m sprints. The fastest time of the two trials was noted as the final agility time (Miller, Herniman, Ricard, Cheatham, & Michael, 2006). A 5-minute rest period was allowed between trials. ICCs for the TT and IAT were .98 and .97, respectively.

Leg press strength

A bilateral leg press test was selected to provide data on maximal dynamic strength through the full range of motion of the muscles involved. Maximal strength of the lower extremity muscles was assessed using concentric 1RM leg press action. Bilateral leg press tests were completed using standard leg press equipment (Body Solid, GLPH 1100, USA), with the subjects assuming a sitting position (about 120º flexion at the hips, 80º flexion at the knees, and 10º dorsiflexion) and the weight sliding obliquely at 45º. A manual goniometer (Q-TEC Electronic Co. Ltd., Gyeonggi-do, S. Korea) was used at the knee to standardize the range of motion. On command, the subjects performed a concentric leg extension (as fast as possible) starting from the flexed position (85º) to reach the full extension of 180º against the resistance determined by the weight. Warm-up consisted of a set of five repetitions at 40-60% of the estimated maximum (Saez de Villarreal, Gonzalez-Bardillo, & Izquierdo, 2008; Arazi & Asadi, 2013). The participants were instructed on how to perform the $8RM_{LP}$ test with proper form and full range of motion. The participants performed an $8RM_{LP}$ test by increasing the load during consecutive trials until they were unable to properly perform lift for 8 repetitions. Three to four subsequent attempts were made to determine the 8RM. A 2-minute break between trials was allowed for rest. The ICC for the $1RM_{LP}$ was .93. To reduce the risk of injuries, participants were instructed to perform the load they were able to lift 8 times. Afterwards the 1RM of each individual was estimated from the following formula (Brzycki, 1993); 1RM = Weight (kg) / 1.0278 – (number of repetitions × 0.0278). The testing procedure was in accordance with the guidelines of the American College of Sports Medicine (Thompson, Gordon, & Pescatello, 2010).

Plyometric training

The plyometric training programs included two days a week (on Sunday and Wednesday) for six weeks (Thomas, et al., 2009). The 6-week training duration was chosen because it is well known that neural and muscular adaptations can occur within this time frame (Miller, et al., 2006; McClenton, Brown, Coburn, & Kersey, 2008; Thomas, et al., 2009). To standardize training procedures, a one-week orientation consisting of two sessions in which the methods and technique of the training programs were demonstrated and discussed. Each training session began at 2:00 p.m and lasted 35-minute, including a 10-minute warm-up (e.g. jogging, stretching and ballistic exercises), a 20-minute training session (DJ or CMJ), and a 5-minute cool-down (e.g. jogging and stretching exercises). The subjects performed five sets of 20 repetitions (Miyama & Nosaka, 2004) of DJ or CMJ with an 8-second interval between jumps. A 2-minute and 72-hour rest period was given between sets and training sessions, respectively. The whole training program was performed on a dry sand surface

(Miyama & Nosaka, 2004; Impellizzeri, et al., 2008). The subjects in the DJ group began by standing on a 45-cm box and were instructed to lead with one foot as they stepped down from the box and landed with two feet on the sand. After sand contact, they were instructed to jump from the sand as quickly and as high as possible (McClenton, et al., 2008). The subjects in the CMJ group performed exercises that began with a countermovement, defined as the flexion of the knees (approximately 90˚). During all exercises, the subjects were instructed to jump for maximal height and minimal contact time. These instructions were intended to maximize jumping height with limited ground contact time (Gehri, et al., 1998). The subjects were instructed to perform the exercises in each training session with maximal effort. During training, all subjects were under direct supervision and were instructed on how to perform each exercise by a certified strength and conditioning specialist. During six weeks, DJ, CMJ and CG continued their normal daily activities, and were instructed not to perform any other type of training (such as resistance training and/or plyometric training) that would impact the results. Adherence to training was 100%, as each subject completed 12 workouts. Missed workouts were compensated for during a scheduled rest day.

Statistical analyses

All data are presented as mean±SD. The training-related effects were assessed using a two-way analysis of variance with repeated measures [group (DJ, CMJ and CG) × time (PRE and POST]. When a significant F value was achieved, Bonferroni post hoc procedures were performed to locate pairwise differences. A criterion α level of .05 was used to determine statistical significance. All statistical analyses were performed with the a statistical software package (SPSS®, Version 16.0, SPSS., Chicago, IL). Moreover, the calculation of effect size (the difference between the pretest and post-test scores divided by the pretest standard deviation) was used to examine the magnitude of any treatment effect.

Results

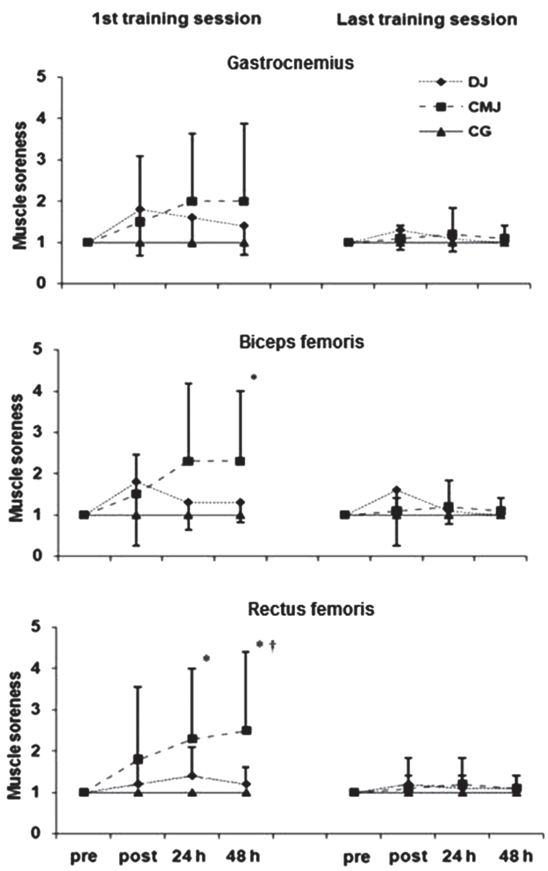
At the beginning of the training program, no significant differences were observed between groups in VJT, SLJT and 20- and 40-m sprints, TT, IAT and $1RM_{LP}$. Moreover, no significant changes were observed in the control group in any variable at post testing.

Perceived muscle soreness

Changes in muscle soreness are presented in Figure 1. There was a significant interaction ($F_{4.4,\,45.9}$=4.70, p=.009), which indicated a greater increase in muscle soreness for the rectus femoris for the CMJ group when compared to the DJ at 48 hours. The CMJ group had significantly greater perception of muscle soreness than the CG at 24 and 48 hours for the rectus femoris after the first training session (p<.05). In the biceps femoris, the CMJ group had significantly greater perception of muscle soreness than the CG at 24 hours after the first training session (p<.05). No significant differences in gastrocnemius soreness were seen for any group. Moreover, no statistically significant differences were observed between groups after the last training session.

Jump performance

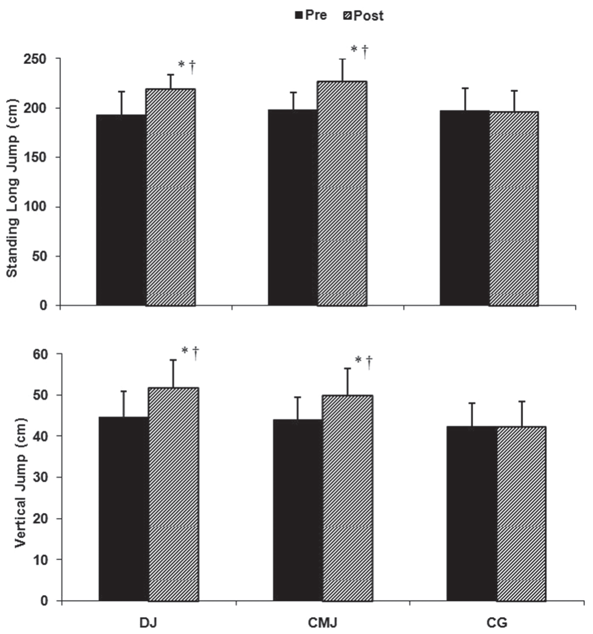
Vertical jump and standing long jump changes are presented in Figure 2. A significant training effect was seen in the experimental groups (DJ and CMJ) for the VJT ($F_{2,27}$=5.86, p=.008) and SLJT ($F_{2,27}$=6.77, p=.004) from pre- to post-training. VJT performance improved significantly in the DJ group (from 44.5±6.4 to 51.7±6.8 cm, 16.2±6.6%, effect



Note: DJ depth jump; CMJ countermovement jump; CG control group.
* Significantly different (p≤.05) from the corresponding CG value.
† Significantly different (p≤.05) from the corresponding DJ value.

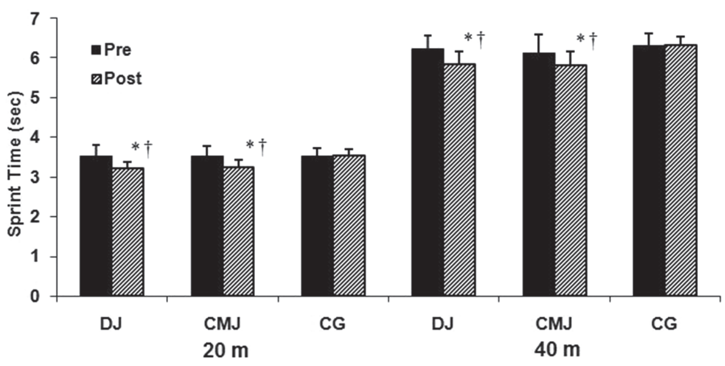
Figure 1. Changes in muscle soreness before (pre), immediately after (post), 24 and 48 hours after DJ and CMJ exercise. Values are M±SD.

size [ES]=1.1) and the CMJ group (from 44.2±5.5 to 50.6±6.4 cm, 13.5±3.4%, ES=1.1); likewise, the SLJT increased values significantly in the DJ group (from 193.5±22.9 to 219±14.6 cm, 13.9±8.7%, ES=1.1) and the CMJ group (from 198.8±16.9 to 227±22.2 cm, 14.4±10.5%, ES=1.6), with no difference between the groups. Both the DJ and CMJ group demonstrated significant differences compared to the CG (p<.05).



Note: DJ depth jump; CMJ countermovement jump; CG control group.
* Significantly different (p≤.05) from the corresponding CG value.
† Significantly different (p≤.05) from the corresponding pre training value.

Figure 2. Changes in vertical jump and standing long jump at pre and post training. Values are M±SD.



Note: DJ depth jump; CMJ countermovement jump; CG control group.
* Significantly different (p≤.05) from the corresponding CG value.
† Significantly different (p≤.05) from the corresponding pre training value.

Figure 3. Changes in 20-m and 40-m sprint tests at pre and post training. Values are M±SD.

Sprint

A significant training effect was observed in the experimental groups (DJ and CMJ) for the 20- ($F_{2,27}$=11.49, p=.001) and 40-m ($F_{2,27}$=8.05, p=.002) sprints from pre- to post-training. Significant reductions in 20-m time (DJ: from 3.5±0.2 to 3.2±0.1 second, 8.5±4.5%, ES=1.5; CMJ: from 3.5±0.2 to 3.2±0.1 second, 7.4±5.5%, ES=1.5) and 40-m time (DJ: from 6.2±0.3 to 5.8±0.3 second, 6.1±3.2%, ES=1.3; CMJ: from 6.1±0.4 to 5.8±0.3 second, 3.8±3.9%, ES=0.75) were observed post training; however, no significant differences were observed between the groups. Both the DJ and CMJ group demonstrated significant differences compared to the CG (p<.05) (Figure 3).

Agility

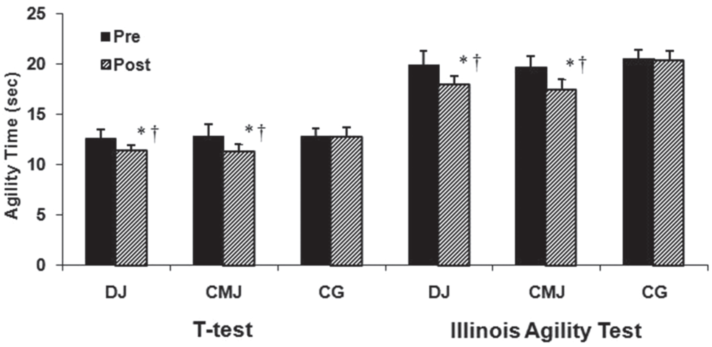
Changes in TT and IAT are presented in Figure 4. A significant training effect was observed in the experimental groups (DJ and CMJ) for the TT ($F_{2,27}$=12.75, p=.001) and IAT ($F_{2,27}$=26.34, p=.001) from pre- to post-training. Significant reductions in TT time (DJ: from 12.6±0.8 to 11.4±0.5 second, 9.3±3.4%, ES=1.5; CMJ: from 12.8±1.2 to 11.3±0.7 second, 12±5.6%, ES=1.2) and IAT time (DJ: from 19.9±1.4 to 18.0±0.7 second, 9.2±4%, ES=1.3; CMJ: from 19.6±1.1 to 17.5±1.0 second, 10.6±5.8%, ES=1.9) were observed in DJ and CMJ post training. Both groups demonstrated significant differences compared to the CG (p<.05); however, no significant differences were observed between the DJ and CMJ groups.

Strength

A significant training effect was seen in the experimental groups (DJ and CMJ) for the $1RM_{LP}$ ($F_{2,27}$=11.49, p=.001) from pre- to post-training. Maximal strength increased significantly in the DJ group (from 216.4±35.5 to 245.9±43.8 kg, 13.8±8.4%, ES=0.81) and the CMJ group (from 219.1±31.5 to 252±32.3 kg, 15.4±9.6%, ES=1). No significant differences were observed between the groups at post training (p>.05) (Figure 5).

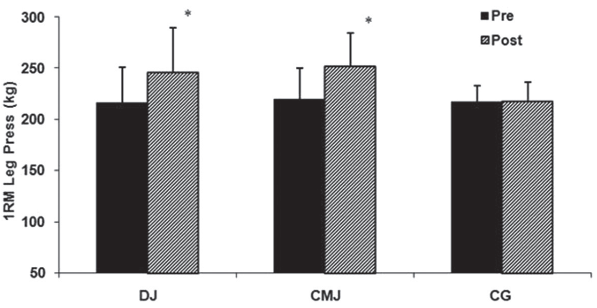
Discussion and conclusions

The novel approach of this study consisted of the comparison of the effects of six weeks of plyometric training on a sand surface between DJ vs. and CMJ groups. The main findings were 1) that gains in muscular performance were induced to equal extent by both training modes; 2) that mus-cular performance gains were similar in both ex-perimental groups, and 3) that muscle soreness



Note: DJ depth jump; CMJ countermovement jump; CG control group.
* Significantly different (p≤.05) from the corresponding CG value.
† Significantly different (p ≤.05) from the corresponding pre training value.

Figure 4. Changes in T-Test and Illinois Agility Test at pre and post training. Values are M±SD.



Note: DJ depth jump; CMJ countermovement jump; CG control group.
* Significantly different (p≤.05) from the corresponding pre training value.

Figure 5. Changes in leg press strength at pre and post training. Values are M±SD.

increased for the treatment groups and these increases were greater for the CMJ group after the first training session, whereas no statistically significant differences were observed between the treatment groups after the last training session.

Muscle soreness

In our study, muscle soreness (e.g. rectus femoris and biceps femoris) increased at 24 and 48 hours post the first CMJ training session with no significant differences between the DJ and CMJ group in muscle soreness (except 48 hours post exercise in the rectus femoris after the first training session). In accordance with our finding, Tofas et al. (2008) found that plyometrics affects not only muscle damage and soreness but also connective tissue and collagen breakdown. Acute increases in soreness and indices of muscle damage such as CK and LDH following plyometric exercise has been established by previous studies (Jamurtas, et al., 2000; Miyama & Nosaka, 2004; Impellizzeri, et al., 2008; Tofas, et al., 2008; Chatzinikolaou, et al., 2010). Moreover, improvements in muscle damage responses (e.g. CK and LDH) in sports involving a strong eccentric action and SSC stimulation are in line with our results from increases in DOMS following intense SSC exercises such as DJ and CMJ training (Ispirlidis, Fatouros, Jamurtas, Nikolaidis, & Michailidis, 2008; Arazi & Asadi, 2013). Strong eccentric action during jumping exercises and a sports event induce high tension to active muscle and connective tissue resulting in muscle damage and soreness (Jamurtas, et al., 2000; Miyama & Nosaka, 2004; Impellizzeri, et al., 2008; Tofas, et al., 2008; Chatzinikolaou, et al., 2010; Arazi & Asadi, 2013; Kostopoulos, et al., 2004). The differences in muscle soreness between DJ and CMJ may be due to higher tension per cross-sectional area of active muscle mass during the CMJ training on sand (Chatzinikolaou, et al., 2010). The limited developments of muscle soreness (<2.5) after exercise suggest that the extent of muscle damage was smaller after DJ or CMJ exercise on sand. The present muscle soreness rise (<2.5) may be considered moderate compared to respective values after eccentric and other exercise protocols (Jamurtas, et al., 2000; Miyama & Nosaka, 2004; Impellizzeri, et al., 2008; Chatzinikolaou, et al., 2010) in a 10-point scale that may be interpreted as limited muscle damage. Perhaps the sand surface made a softer environment for the DJ or CMJ training. On the other hand, the use of a softer surface may be useful during intensified training period to reduce the stress on the musculoskeletal system (Miyama & Nosaka, 2004). Although we did not measure other indirect indices of muscle damage (e.g. CK, LDH, and myoglobin), it is likely that the lower leg muscle soreness was related to smaller muscle damage and hence less stress on the musculoskeletal system (Miyama & Nosaka, 2004; Impellizzeri, et al., 2008). This finding may be attributed to the lower eccentric action of the present protocol and the execution of plyometric jumps on a soft surface (sand) that induces less muscle damage than a firm surface (Miyama & Nosaka, 2004). Moreover, the soreness was relatively low following the 6-week training on sand and it could allow neural adaptation to these exercises including: (a) inter-muscular coordination and (b) changes in stretch reflex excitability (Markovic & Mikulic, 2010).

Muscular performance

Jumping ability increased significantly for both the DJ and CMJ groups. Our findings are in accord with those of, Gehri et al. (1998) and Thomas et al. (2009) who reported significant improvement in jump height after 12 and six weeks of DJ and

CMJ training on solid surface with no differences between them. In spite of the fact that jumping on sand causes a lower reuse of elastic energy and energy loss due to feet slipping during the concentric action (Giatsis, et al., 2004; Miyama & Nosaka, 2004), we found greater in-creases in jumping ability (~14%) compared to the previous studies (~5%). The discrepancy between the magnitude of jumping ability increases evident in the results of the present research and the results from previous studies might be attributed to the fact that the subjects in the present study were not specialists in plyometric training or used any other type of training surface, in contrast to the greater training experience and initial training status of subjects in previous research. Furthermore, the great improvements in vertical jump ability in these experimental studies could be related to the neural adaptation (McClenton, et al., 2008; Saez de Villarreal, et al., 2009; Markovic & Mikulic, 2010). According to the previously mentioned authors, neuromuscular factors such as increasing the degree of muscular coordination, increasing inhibition of antagonist muscles as well as activation and co-contraction of synergistic muscles and "motor unit functioning" appear to be more important for increasing scores in VJT and SLJT following plyometric training on sand (McClenton, et al., 2008; Saez de Villarreal, et al., 2009; Markovic & Mikulic, 2010). Moreover, muscles' inhibitory proprioceptors, called Golgi-tendon organs, respond to an increased muscle tension and ultimately prevent the muscle from becoming overstretched. This reflex is detrimental to improving jump due to the limitations the Golgi-tendon organs place on generating muscle stretch. The inhibitory effect of the Golgi-tendon organs is smaller than the facilitating effect of the muscle spindles; therefore, it is thought that the inhibitory effect can be offset as a result of the sand plyometric training (Lees & Graham-Smith, 1996).

Compared to the results of Markovic et al. (2007) and Thomas et al. (2009), the current rate of improvements in sprint was greater. Markovic et al. (2007) examined the effects of a 10-week plyometric training (e.g. DJ and hurdle jumps) on 20-m sprint time and did not find any significant changes. Also, Thomas et al. (2009) compared the effects of DJ vs. CMJ training on 5, 10, 15 and 20-m sprints and did not find any significant improvements. It seems that the differences in training intensity, training volume and sample size could be the reason of the discrepancy in results. In our study we found significant improvements in 20-and 40-m sprints. These findings are in line with the previous authors who reported significant decreases in sprint time following plyometric training (Rimmer & Sleveret, 2000; Saez de Villarreal, et al., 2008; Saez de Villarreal, et al., 2012; Arazi & Asadi, 2012). For instance, Impellizzeri and co-workers (2008) reported that plyometric training on sand improved 10- and 20-m sprint. Young (1992) also suggested that jumping could be a specific exercise for the development of acceleration because the contact times of jumping and sprinting during the initial acceleration phase are very similar. It is possible that a training program that incorporates changes in stride length and stride frequency (i.e. skipping, jumps with horizontal displacement) or combined with strength/power training would result in the most beneficial effects (Rimmer & Sleveret, 2000; Saez de Villarreal, et al., 2010). The absorptive qualities of sand are likely to increase contraction time and allow the leg extensor muscles to build up active state and force prior to shortening. This would enable subjects to produce more work on sand than on land. This mechanism could be an important reason for improving sprint performance following sand plyometric training.

Time to complete the IAT and TT decreased for both experimental groups. These results are supported by findings in the literature (Miller, et al., 2006; Arazi, et al., 2012). For instance, Thomas et al. (2009) compared the effects of six weeks of DJ and CMJ training on agility (505 agility test) in young soccer players and found that DJ and CMJ plyometric training could positively affect agility performance, with no significant differences between the modes. Agility improvement requires rapid force development and high power output, and it seems that DJ and CMJ training on sand can improve responses to these requirements (Thomas, et al., 2009). Moreover, agility tasks require a rapid switch from eccentric to concentric muscle action in the leg extensor muscles (the SSC muscle function). Thus, it has been suggested that SSC training (DJ and CMJ) can decrease ground reaction times due to an increase in muscular force output and movement efficiency, positively affecting the agility performance (Markovic & Mikulic, 2010). Although the previously mentioned authors have reported increases (~5%) in agility performance (Miller, et al., 2006; Thomas, et al., 2009), we found greater increases (~12%) resulting in greater neuromuscular adaptations related to firing frequencies and enhancement of motor unit recruitment (Miller, et al., 2006; Hakkinen, Alen, & Komi, 1985); however, as we could not exactly determine that neural adaptations or better facilitation of neural impulse to spinal cord occurred, further studies are required to determine the mechanisms of agility improvement via plyometric training.

In the current study, the $1RM_{LP}$ scores increased signi-ficantly in the DJ and CMJ training groups, whereas no significant differences were observed between the groups. Numerous studies demonstrated im-provements in strength via plyometric training (Robinson, et al., 2004; Saez de Villarreal, et al., 2008; Arazi & Asadi, 2011). In contrast, a number of authors failed to report significant positive effects of plyometric training on strength (Markovic, et al., 2007). Several studies have reported significant correlations between muscular strength and sprinting speed (Alexander, 1989; Young, McLean, & Ardagna, 1995). Young et al. (1995) reported significant correlations between strength per body mass measures and starting ability (r=.86), acceleration out of the block (r=.64), and maximum sprinting speed (r=.80). Canavan, Garrett, and Armstrong (1996) reported significant kinetic relationship between Olympic lifts and vertical jump performance. In the present study, $1RM_{LP}$ increased significantly in both experimental groups. Our findings are similar to those of Fatouros et al. (2000) who reported that development of power is a significant factor for increasing maximal strength. It is likely that the improvements observed in lower-body strength contributed to the improvements in both the jumping and sprinting performance observed in the present study. Several studies have indicated the importance of plyometric training for improving vertical jump and sprint performance (Giatsis, et al., 2004; Markovic, 2007; Arazi & Asadi, 2011; Arazi, et al. 2012). The strength increases are supported by previous studies, which have shown the effectiveness of plyometric training for developing power resulting muscular strength enhances (Saez de Villarreal, et al., 2008; Arazi & Asadi, 2011). Moreover, it is likely that mechanism(s) such as enhanced motor neuron excitability, increased motor unit recruitment, or increased activation of synergists or all, resulting from the CMJ on sand, may have contributed to an increase in $1RM_{LP}$ performance in our investigation (Saez de Villarreal, et al., 2009; Arazi & Asadi, 2011). Plyometrics on sand surface develops larger and stronger leg musculature and causes more energy to be spent per unit of time than plyometrics on hard ground. Sand acts as a resistance that provides longer time under tension to the muscles and involves more muscle fibres in order to jump, which is a precursor to muscle strength increase.

We suggest that in the context of moderately trained subjects these observations may have important practical relevance for the optimal design of plyometric training programs, given that plyometric training on sand surface is efficient for improving jumping and sprinting ability, agility and strength performance. To what extent the present results are also applicable to more experienced trained athletes or various types of sports needs to be further examined. The magnitude of increases in the dependent variables may be attributed to compliance, friction and instability properties of sand surface, resulting increases in muscle tension, higher tension per cross-sectional area of active muscle mass and increased motor unit recruitment due to DJ and CMJ training on sand.

In conclusion, the current findings indicate the benefits of DJ and CMJ plyometric training on sand for improving jumping and sprinting ability, agility and strength performance. They also support the fact that increases in perfor-mance can occur after six weeks of DJ and CMJ training on sand with minimal muscle soreness and damage to lower body. It is recommended that coaches design plyometrics on sand because these types of training on sand can be an effective form of training for improving performance with less muscle soreness. These observations may have considerable practical relevance for the optimal design of plyometric training programs, given that a DJ and CMJ training on sand is efficient for improving muscular performance and it was concluded that plyometric exercises with DJ and CMJ characteristics are best used in developing muscle performance of the lower extremities. Our investigation also suggests that DJ and CMJ performed on sand surface are less stressful for the muscle-tendon complex, and this may have implications for rehabilitation and in the prevention of musculoskeletal injury. To what extent the present results are also applicable to more experienced trained athletes or various types of sports needs to be further examined. In addition, with regard to the results of this study and the connection between sand events in beach volleyball and sand plyometric training effects, we can recommend that athletes, especially beach volleyball players, use DJ and CMJ training on sand in their conditioning cycle (i.e. pre-season) as it may increase the rate of performance improvement. Depending on which qualities the practitioner wishes to improve, this knowledge can be useful to ensure effective training improvements. Notably, no dropouts attributable to injury or injury symptoms were experienced in treatment groups throughout the training period, whereas significant gains in maximal strength and power were achieved with less muscle soreness after six weeks of training on sand.

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UČINCI ŠEST TJEDANA TRENINGA DUBINSKIH SKOKOVA I SKOKOVA S PRIPREMOM NA PIJESKU NA MIŠIĆNI ZAMOR I IZVEDBU

Cilj je ovog istraživanja bio utvrditi učinke šestotjednog treninga dubinskih skokova u odnosu na skokove s pripremom na pijesku na mišićni zamor, izvedbu skokova, sprinta, agilnost i snagu nožnog potiska. Za sudjelovanje u istraživanju volontiralo je 30 ispitanika (dob: 20,4±1,1 godina; tjelesna visina: 177,4±5,1 cm; tjelesna težina: 72,8±9,7 kg) koji su slučajnim odabirom raspoređeni u jednu od tri grupe: grupu koja je trenirala dubinske skokove (n=10), grupu koja je trenirala skokove s pripremom (n=10) ili kontrolnu grupu (n=10). Ispitanici u eksperimentalnim grupama provodili su trening dubinskih skokova ili trening skokova s pripremom dva puta tjedno tijekom šest tjedana. Program treninga uključivao je pet serija po 20 ponavljanja dubinskih skokova (saskok sa sanduka visine 45 cm) ili skokova s pripremom na suhom pijesku dubine 20 cm. Tjedan dana prije treninga te nakon šest tjedana treninga provedena su mjerenja visine vertikalnog skoka, skoka udalj s mjesta, sprinta na 20 i 40 metara, razine agilnosti pomoću T-testa i *Illinois Agility Testa* te 1RM u testu nožni potisak. Razina mišićnog zamora također je bila mjerena prije, odmah nakon, 24 i 48 sati nakon prvog i posljednjeg treninga. Značajna povećanja u visini vertikalnog skoka (16,2 vs. 13,5%) i skoku udalj s mjesta (13,9 vs. 14,4%) (p<0,05) zabilježena su u grupi koja je trenirala dubinske skokove, odnosno skokove s pripremom. Značajna smanjenja vremena sprinta na 20 (8,5 vs. 7,4%) i 40 (6,1 vs. 3,8%) metara, T-testu (9,3 vs. 12%) i Illinos Agility Testu (9,2 vs. 10,6%) zabilježena su u obje eksperimentalne grupe. Značajno povećanje 1RM u testu nožni potisak zabilježeno je samo u grupi koja je provodila trening skokova s pripremom. Ista grupa zabilježila je i statistički značajno veći osjećaj mišićnog zamora u mišiću *rectus femoris* 48 sati nakon prvog treninga nego grupa koja je provodila trening dubinskih skokova i kontrolna grupa. Nisu zabilježene statistički značajne razlike u osjećaju zamora između grupa nakon posljednjeg treninga. Rezultati ovog istraživanja mogu pridonijeti dizajniranju optimalnih programa pliometrijskog treninga, s obzirom na činjenicu da su oba eksperimentalna tipa treninga na pijesku pokazala učinkovitost u poboljšanju mišićnih performansi.

Ključne riječi: *dubinski skok, skok s pripremom, ciklus istezanja i skraćivanja mišića, pijesak, mišićno oštećenje*