Monten. J. Sports Sci. Med. 5 (2016) 2: 17–23
Original scientific paper
UDC 796.012.12:612.171

Perceived Muscle Soreness, Functional Performance and Cardiovascular Responses to an Acute Bout of Two Plyometric Exercises

Hamid Arazi
University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, Rasht, Iran
Abbas Asadi
University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, Rasht, Iran
Roudbar Branch, Islamic Azad University, Roudbar, Iran
Jabar Chegini
University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, Rasht, Iran

ABSTRACT

Although a few studies examined the effects of plyometric exercise on cardiovascular responses and symptoms of muscle damage, the data about the different types of plyometric exercise such as eccentric-based vs. concentric-based exercise is scarce. The purpose of the present investigation was to compare the effects of eccentric and concentric-based plyometric exercises on post-exercise systolic (SBP) and diastolic blood pressure (DBP), heart rate (HR) and symptoms of muscle damage. Nineteen healthy men volunteered to participate in this study and were randomly assigned to two groups: Depth jump group (DJG; N=9; Eccentric) and Box jump group (BJG; N=10; Concentric). After plyometric exercise SBP, DBP and HR were measured every 10 min for a period of 90 min post-exercise. Also, muscle soreness, vertical jump and 10-m sprint were assessed at 24, 48, and 72 h post-exercise. There were no significant changes in SBP and DBP, and no significant differences between groups in SBP and DBP, whereas the DJG showed greater increases in HR when compared with BJG. Both the groups indicated significant differences in muscle soreness, vertical jump and 10-m sprint at 24, 48 and 72 h post-exercise without significant differences between them. The findings of this study demonstrated that there were no differences in SBP and DBP between groups and both groups showed increases in symptoms of muscle damage following plyometric exercise.

Key words: *Blood Pressure, Heart Rate, Plyometric Exercise, Soreness, Performance.*

Introduction

Plyometric jump training is characterized by a series of exercises involving hops and jumps used to capitalize on the stretch shortening cycle of the muscle (Chu, 1998). Plyometrics consists of a rapid stretching of a muscle (eccentric phase) immediately followed by a concentric or shortening action of the same muscle and connective tissue. The stored elastic energy within the muscle is used to produce more force than can be provided by a concentric action alone (Chu, 1998). It is believed that training with plyometrics facilitates adaptations in muscle function that will increase an athlete's explosive power, which is defined as force time's distance over time (Chu, 1998). Plyometrics has been shown to be an effective method in increasing lower-body power, as measured by vertical jump, sprint and overall athletic performance (Carlson, Magnusen, & Walters, 2009, Arazi, & Asadi, 2011, 2012, Arazi, Coetzee, & Asadi, 2012).

It has been well documented that eccentric muscle contractions during plyometric exercise (PE) induced more force and tension in the cross sectional area of active muscle fibers. These tension and force during eccentric exercise induced muscle damage and soreness, particularly when the muscles were unaccustomed to this type of exercise (Tofas et al., 2008). In comparison of eccentric-based vs. concentric-based PE on acute symptoms of muscle damage, Jamurtas et al. (2000) reported that an acute bout of eccentric exercise induced greater muscle damage than concentric exercise. Frequently observed acute symptoms of plyometric exercise include muscle soreness (Twist, & Eston, 2005), increase in plasma creatine kinase activity (Tofas et al., 2008, Chazinikolaou et al., 2010), loss of strength (Chazinikolaou et al., 2010) and power (Byrne, & Eston, 2002) and a reduction in joint range of motion (Chazinikolaou et al., 2010, Eston, & Peters, 1999). Although above authors explored the effects of plyometric exercise on anaerobic-type activities (e.g., power and sprint), there were a few data about this type of exercise on aerobic components. It has been well reported that aerobic variable of physical fitness is important for enhancing performance, daily life activity and health, therefore, this component can be improve by PE resulting cardiovascular stimulations and their effects on heart rate and blood pressure (MacDonald et al., 1999, Pescatello et al, 2004, Brown et al., 2010, Arazi et al., 2012). Moreover, it seems that PE may induce benefits on VO2max, running economy and other components of aerobic activities. Blood pressure (BP) and heart rate are vital components for cardiovascular and aerobic-type activity measures. It appears that resistance and endurance exercise/training has significant effects on the management of blood pressure and decreases resting heart rate (MacDonald et al., 1999, Pescatello et al, 2004). Newly, plyometric exercise is widely used in athletes for increasing functional performance, but

Received for publication March 31, 2016

the information about this kind of exercise on cardiovascular system; especially on BP is not completely understood.

To our knowledge, a few studies have investigated the BP responses following plyometric exercise, and these studies have shown conflicting results (Arazi et al., 2013, 2014). Previous studies showed that plyometric exercise could increase BP after each set of exercise (Brown et al., 2010, Arazi et al., 2012), but the information about the effects of plyometric exercise on post-exercise hypotension is scarce and no study examined this approach. Moreover, eccentric and concentric phases in plyometrics have differences in stretch-shortening cycle pattern. During eccentric phase, elastic energy stored within the muscle and during concentric phase this energy released. When the PE go to more time between eccentric to concentric exercise the elastic energy change to heat and can influenced on the efficiency of PE and resulting worsens of aerobic and anaerobic performances (Chu, 1998, Arazi, Coetzee, & Asadi, 2012). Depth jump exercises is one of the best exercise in increasing performance and include fast SSC jump (eccentric-based exercise) and Box jump exercise is concentric-only jump (Chu, 1998, Arazi et al., 2013, 2014).

With regard to differences between two types of PE in SSC pattern and performance, the data about these types of PE on cardiovascular and muscle function after a session of exercise is scarce. Therefore, the purpose of this study was to examine the influence of a session of depth jump (eccentric-based exercise) vs. box jump (concentric-based exercise) exercises on post-exercise hypotension (PEH), muscle soreness and functional performance.

Methods

Participants

Nineteen healthy men, who were familiar with plyometric exercise and training, volunteered to participate in this study and were randomly assigned to two groups: Depth jump group (DJG; N=9: age, 20.8±1.3 years; height, 173.6±5.3 cm; and weight, 67.4±7.4 kg) and Box jump group (BJG; N=10: age, 20.8±1.3 years; height, 174.7±5.5 cm; and weight, 70.1±7.7 kg). The subjects were healthy, free from any lower body injuries and had not medical, cardiovascular and orthopedic problems that were confirmed by physician. Before data collection, participants were informed about the nature, benefit, and potential risks of the study, and signed a written informed consent form before beginning the study and the University Human Subjects Institutional Review Board approved all testing and training protocols.

Study Design

The data collection was performed on five consecutive days with 24 h interval between sessions and testing sessions were performed between 2:00 and 4:00 PM. At the first session, subjects recruited to laboratory for the measurement of age, weight and height. During this session, each participant was instructed to proper form and technique of depth jump and box jump exercises and was tested for the baseline of delayed onset muscle soreness (DOMS), vertical jump (VJ) and 10-m sprint. At the second session, subjects reported to laboratory and performed plyometric exercise. Before performing the depth jump or box jump exercise, the subjects performed 10 min warm-up including light running, static stretching and ballistic movements, and then remained seated for 10 min, in a calm and quiet environment. Then, the HR and BP were measured based on pre-exercise value. Then they performed plyometric exercises for 20 min. Also after performing the protocols, subjects seated for 90 min in a quiet and comfortable place, to measure the post-exercise BP every 10 min. An experienced appraiser performed the measurements at before and after exercise for all subjects. In exercise session, rating of perceived exertion was also assessed after each set of exercise. At day 3, 4 and 5, only subjects were reported to laboratory for measuring DOMS, VJ and 10-m sprint tests. The ambit temperature was fixed at 27±1 C° and the air humidity during the tests ranged between 60% and 70%.

Plyometric Exercise

After a 10-min warm-up, participants performed plyometric protocols including 5 set of 20 repetitions box jumps on a 50-cm box (concentric-only jump) and 5 sets of 20 repetitions depth jumps from a 50-cm plyometric box (eccentric jump). Participants had a 2 min rest between sets and 8 seconds interval between jumps.

Box jump procedure: Subjects stood in an upright position, with their feet shoulder-width apart. When the subjects were ready to jump, they dropped quickly into a quarter squat, then extended their hips, swing their arms, and pushed their feet through the floor to propel themselves onto the 50-cm box (Asadi, 2014).

Depth jump procedure: Subjects in the DJ group began by standing on a 50-cm box and were instructed to lead with one foot as they stopped down from the box and landed with two feet on the land. After land contact, they were instructed to explode off the land by jumping as quickly and as high as possible (Arazi et al., 2013, 2014).

Blood Pressure and Heart Rate Measurements

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured by the indirect auscultatory method using a sphygmomanometer (Missouri®) and stethoscope (Rappaport® GF Health Products, Northeast Parkway Atlanta). The BP was assessed before the exercise bout and at 10 min interval for 90 minutes after the exercise bout. The HR was measured using Polar S610i heart rate monitor (FIN, 90440, FINLAND) (beat/min).

Rating of Perceived Exertion (RPE)

The rating of perceived exertion (RPE) using the Borg 6-20 RPE Scale 19 was recorded immediately following each set of jumps. After the final repetition, participants were reminded to think about feelings of exertion in the active muscle group, in accordance with previous procedures (Brown et al., 2010, Asadi, 2014).

Delayed Onset Muscle Soreness (DOMS)

Each participant was asked to indicate perceived muscle soreness of the knee extensors using a visual analogue scale. The scale was numbered from 1 to 10 (on the reverse side of the sliding scale) with 1 indicating no muscle soreness and 10 signifying that the muscle was too sore to move. With hands on hips and squatting to an approximate knee angle of 90 deg, participants were asked to indicate the level of perceived soreness based on the rating scale. This corresponded to the location of perceived muscle soreness on the continuum (Tofas et al., 2005, Chatzinikolaou et al., 2010).

Vertical Jump (VJ)

The VJ height was assessed using the VERTEC jump system. Jump height was assessed with a rapid preparatory downward eccentric movement, which utilized the stretch-shortening cycle followed by a maximal jump. Before the assessment of jump height, all participants received a standardized warm-up of three sub-maximal continuous jumps. Participants performed three maximal jumps and the highest jump height was used for further analyses. Participants were encouraged to perform their maximal capacity and to try to jump higher than their previous jump (Asadi, & Arazi, 2012).

10-m Sprint

The participants performed 2 sets of a single 10-m sprint from a standing start on an indoor track with a 3-min recovery. Sprint time was recorded using 2 electronic photo cells positioned at 0 (start) and 10-m. Time for sprint performance was recorded to the nearest 0.01 second via telemetry to a handheld system. The fastest time recorded was used for analysis (Twist, & Eston, 2005).

Statistical Analyses

Data are presented as mean ± SD. Data normality was checked and verified with the Kalmogorov-Smirnoff test. A repeated-measures ANOVA (2 × 10, group × time) was used to analyze SBP, DBP and HR data (SPSS 16.0). To assess changes in RPE between sets, a 2 (group) × 5 (set) ANOVA was applied to the data. Also, to assess changes in DOMS, VJ and 10-m sprint, 2 × 4 (group × time) ANOVA was used to the data. When a significant F value was achieved, a Bonferroni post hoc test was used to detect differences in the measures. Significant level was set at $p < 0.05$.

Results

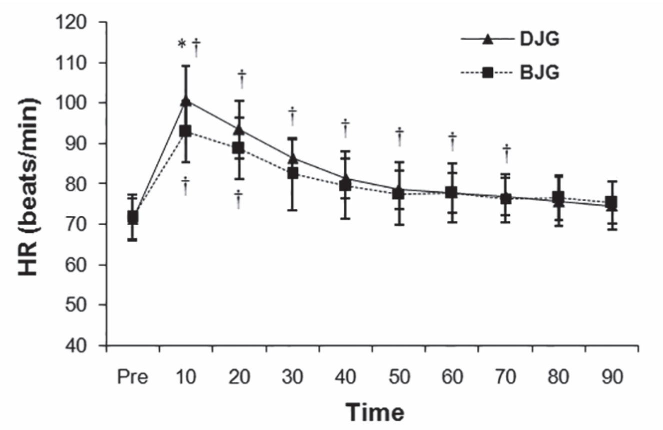
At the beginning of the study, no significant differences were observed between groups in SBP, DBP, HR, DOMS, VJ and sprint ($p > 0.05$).

Table 1. Changes (mean ± SD) in systolic (SBP) and diastolic blood pressure (DBP) at pre and 90 min post Depth jump (DJG) and Box jump (BJG) plyometric exercise.

Time	DJG		BJG	
	SBP (mm Hg)	DBP(mm Hg)	SBP (mm Hg)	DBP (mm Hg)
Pre-exercise	119.1±6.1	75.8±4.2	115.8±8.1	77.1±5.7
10th min	124.2±7.2	75.6±3.7	121.9±8.3	78.3±8.2
20th min	120.8±7.3	76.5±4.6	115.3±9.2	75.5±6.4
30th min	118.2±8.4	75.2±4.6	113.1±7.3	74.6±7.1
40th min	115.7±9.1	74.4±5.7	112.7±8.4	74.6±7.2
50th min	115.3±8.8	74.3±5.5	112.5±9.4	74.8±7.1
60th min	116.4±8.4	74.3±5.2	113.1±9.6	73.8±5.1
70th min	117.5±8.3	75.2±4.8	113.2±8.6	75.2±6.8
80th min	117.2±7.1	74.8±4.9	113.5±8.4	75.3±6.8
90th min	117.4±6.7	75.1±4.9	113.5±8.8	75.1±6.9

Means and SD for SBP and DBP values are presented in Table 1. No significant differences were observed between post-exercise SBP when DJG and BJG were compared. Although the changes in SBP for both the DJG and BJG were not statistically significant, in the SBP the DJG showed increases until 30 min post-exercise and after this point the SBP decreased, whereas the BJG showed increases in 10 min post-exercise and after this point the SBP decreased. No statistically significant changes were seen between groups in DBP and the changes in DBP were not significant for the both groups.

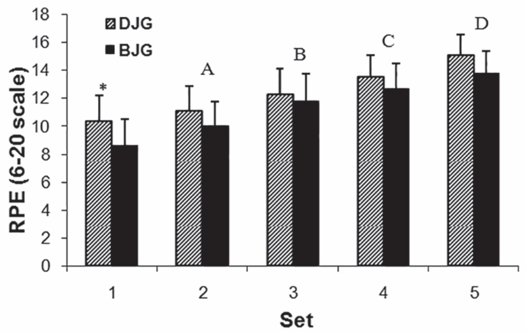
Significant differences were observed between post-exercise HR at 10th min when DJG and BJG were compared (F3.9, 66.4GG=3.5, $p < 0.05$). The DJG showed significant increases in HR until 70 min post-exercise, whereas the BJG showed significant increases until 20 min post exercise when compared to pre-exercise (Figure 1).



Legend: * Significant differences (p< 0.05) compared with BJG; † Significant differences (p< 0.05) compared with pre-exercise value.

Figure 1. Changes (mean ± SD) in heart rate (HR) at pre and 90 min post Depth jump (DJG) and Box jump (BJG) plyometric exercise

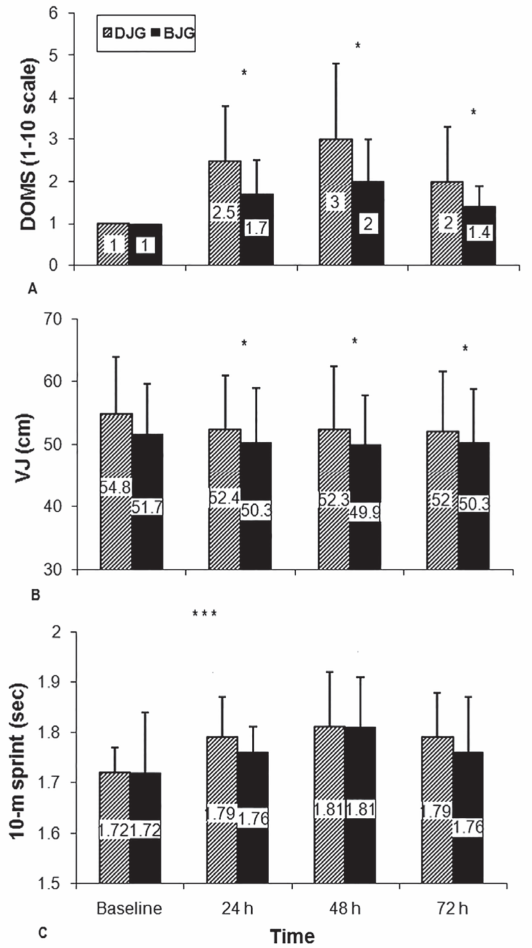
The RPE increased progressively throughout the plyometric exercises (DJG and BJG), with set 2 being harder than set 1, set 3 harder than set 1 and 2, set 4 being harder than set 1, 2 and 3, and set 5 being harder than set 1, 2, 3 and 4. A significant interaction of time and group (F1.7, 28.5GG=125.5, $p < 0.05$) demonstrated that the DJG displayed an increase in perceived exertion greater than BJG at set 1 (Figure 2).



Legend: * Significant differences (p< 0.05) compared with BJG; A Significant differences (p< 0.05) compared with set 1; B Significant differences (p< 0.05) compared with set 1 and 2; C Significant differences (p< 0.05) compared with set 1, 2 and 3; D Significant differences (p< 0.05) compared with set 1, 2, 3, and 4.

Figure 2. Changes (mean ± SD) in rating of perceived exertion (RPE) during 5 set of Depth jump (DJG) and Box jump (BJG) plyometric exercise

The DOMS significantly increased in DJG and BJG at 24 h post-exercise, peaked at 48 h and remained elevated for 72 h during recovery ($F_{1.9,\ 32.3GG}=14.3$, $p < 0.05$). Although, there were no significant differences between groups, the DOMS was greater for the DJG at all time points (Figure 3).



Legend: * Significant differences (p< 0.05) compared with baseline value for both groups.

Figure 3. Changes (mean ± SD) in delayed onset muscle soreness (DOMS, A), vertical jump (VJ, B) and 10 m sprint performance (C) at baseline and 24, 48, and 72 h post Depth jump (DJG) and Box jump (BJG) plyometric exercise

The VJ performance changes are shown in figure 3 B. The VJ declined 24 h post-exercise and remained significantly below baseline until 72 h within recovery (F2.7, 44.2GG=8.5, $p < 0.05$), however there were no significant differences between groups.

Sprint time in the DJG and BJG over 10-m were significantly increased at 24 h, peaked 48 h and remained elevated for 72 h during recovery (F2.3, 38.7GG=6.5, $p < 0.05$). No significant differences between groups were seen in 10-m sprint (Figure 3 C).

Discussion

With regard to important role of plyometric exercise and training on improving muscular performance, the effects of this type of exercise on acute cardiovascular responses is important and few studies focused on this area and information about this aspect is very little. Also, to the best of our knowledge no study compared eccentric and concentric plyometric exercises on blood pressure and heart rate responses and symptoms of muscle damage. Therefore, this study was designed to examine the effect of a bout of plyometric exercise with differing in pattern (eccentric-based vs. concentric-based) on PEH, HR, and symptoms of muscle damage such as DOMS, VJ performance and 10-m sprint in men.

The results indicated that, however, SBP increased after both PE, these changes were not statistically significant. Also, differences in DBP were not remarkable changes after PE. Although, HR increased progressively for both the groups and these increases were higher for DJG. These findings are in agreement with Brown et al. (2010) who reported no significant changes in post-exercise SBP and DBP. In contrast, Arazi et al. (2013, & 2014) reported decreases or increases after PE on SBP and DBP in normotensive men and or in athletes, respectively. The possible mechanisms for these differences could be subjects' status and different PE protocol. Moreover, the exact mechanisms responsible for these responses are unclear. It is possible that high intensity PE induces an increase in sympathetic nerve activity to the heart and blood vessels and altered vascular responsiveness during exercise resulting not remarkable increases in systolic blood pressure (Arazi et al, 2014). Although, no study compared eccentric and concentric plyometric exercise on DBP, therefore it is difficult to compare our results with those of other investigators. The possible mechanism(s) for unchanged DBP could be interactions between increases in cardiac output and decreases in blood vessel resistance (Asadi, 2014). The increases in HR after PE were confirmed by several studies (Brown et al. 2010, Arazi et al. 2012, 2013, 2014). In our previous studies, we examined the effects of DJ exercise with different intensities and workloads on post-exercise HR responses and found significant increases in HR until 50 min post-exercise (Arazi et al. 2012, 2013, 2014). In the current investigation we examined eccentric vs. concentric type of plyometric exercise and found greater HR for eccentric exercise. The mechanism(s) for this response could be force and intensity of PE and greater involvement of the fast twitch muscle fibers and the size of active muscle mass resulting increases in HR (Arazi et al. 2012, 2013, 2014). In addition, the increases local muscle metabolites and/or heat production are also potential stimuli for the increases heart rate responses after PE (Halliwill, Taylor, & Eckberg, 1996). On the other hand, a decrease in muscle cell pH following PE may stimulate chemosensitive afferent fibers, thereby elevating HR (Victor, Bertocci, & Pryor, 1988). It seems that these responses are greater for DJG vs. BJG. Also, another explanation for the difference in HR between the DJG compared to the BJG may be that the DJG completed 2 jumps per repetition compared to the DJG which only completed 1 jump per repetition.

The RPE increased progressively for both the groups and these increases were greater for DJG. These findings are in line with previous authors who reported progressively increases in perceived exertion during PE (Brown et al. 2010, Arazi et al. 2012, Asadi, 2014a, 2014b). In contrast, Ebben et al. (2008) compared EMG activity during these two exercises, and determined that the BJs were more intense because EMG activity was higher. In a study by Asadi (2014a) the DJ exercise was harder than BJ exercise. The differences between these studies and Ebeen's study could be number of repetitions. It seems that 2 repetitions (Ebben, Simenz, & Jensen, 2008) could not stimulate motor cortex and resulting low intensity (Asadi, 2014a, 2014b), whereas we used 20 repetitions. During the negative phase of a plyometric jump, eccentric activation produces higher tension per cross-sectional area of active muscles mass compared with concentric actions resulting significant perceived exertion (Armstrong, Oglivie, & Schwane, 1983). Therefore, we can say that DJ (eccentric) plyometric exercise is harder than BJ (concentric-only jump) exercise and the results of HR confirmed this conclusion.

Muscle soreness developed following DJ and BJ exercises. Determining muscle damage by using visual analogue scale is the best no invasive method and were used in several studies and appeared high relationship with other muscle damage indicators such as serum CK activity (Jamurtas et al. 2000, Twist, & Eston, 2005). These findings are in line with previous researches who reported DOMS increased significantly following plyometric exercise, peaking between 24 and 48 h, and remained elevated for 72 h (Tofas et al. 2008, Twist, & Eston, 2005, Chatzinikolaou et al. 2010). The present DOMS rise (~ 3) may be considered moderate compared with the respective values after eccentric exercise protocols (Armstrong, Oglivie, & Schwane, 1983) in a 10-point scale that may be interpreted as limited muscle damage. Moreover, we found no significant differences between DJG and BJG in DOMS, but DJG showed greater perceived soreness compared to BJG. It appears that eccentric exercise (DJ) induce greater soreness than concentric-only jump (BJ), because the action of landing from the box generates forces and momentum in the lower extremities that accelerate hip and knee flexion and ankle dorsiflexion (Tofas et al. 2008, Chatzinikolaou et al. 2010). To resist the impact of landing, the knee extensor muscles perform an eccentric action that involves a counter extension movement to absorb kinetic energy (Devita, & Skelly, 1992). It seems likely that these repetitive eccentric muscle actions caused muscle soreness to the knee extensors following the DJ exercise.

The VJ height and 10-m sprint were impaired in the treatment groups. These findings are consistent with previous studies that reported a change in VJ and 10-m sprint performance following plyometric exercise (Twist, & Eston, 2005, Byrne, & Eston, 2002, Chatzinikolaou et al. 2010). It appears that the decreases in VJ height and sprint performance are an artifact of the loss in force-generating capability of the knee extensors following muscle damage and restriction of muscle fiber to contraction by PE (Ingalls et al. 1999, Warren et al. 1993). Previous studies have indicated a reduced excitation-contraction (E-C) coupling efficiency due to a reduction in calcium release per action potential, have shown maximal force production is concurrently impaired for several days following PE (Ingalls et al. 1999, Warren et al. 1993). Therefore a reduction in force-generating capability due to E-C coupling fatigue would unsurprisingly reduce the ability of the muscle to produce power and maximal jump (Ingalls et al. 1999).It is plausible that repeated stretching of the quadriceps during plyometric jumping might have led to preferential disruption in type II muscle fibers (Warren et al. 1993, Brockett et al. 2002, Friden, & Lieber, 1992) as a result of early fatigue and temporary increases in muscle stiffness caused within these fibers by the eccentric component (Enoka, 1996). These fibers would then be less able to contribute to force and power generation following the PE and therefore decreases the VJ height and sprint performance (Ingalls et al. 1999, Enoka, 1996). Also, it appears that the rate of muscle glycogen resynthesis being lower in damaged muscle following PE (Asp et al. 1998). With regard to this evidence, it is possible that PE induced impair muscle glycogen metabolism resulting decreases in jump and sprint performance (Asp et al. 1998, Semark et al. 1999).

In summary, we found that plyometric exercise induced significant increases in HR, DOMS, and decreases in VJ and sprint performance and these changes are greater for eccentric type plyometric exercise; however these differences between groups were not statistically significant. Also, with regard to greater responses in HR and RPE, we found that DJ exercise is harder than BJ exercise and both types of exercise had not statistically positive effects on changing post exercise blood pressure. Thus, it is important for coaches and athletes to note that plyometric depth jump is harder and more aggressive than box jump training with no affects on blood pressure. Further research is needed to examine effects of plyometric exercise with differing in pattern and intensity on PEH and symptoms of muscle damage for increasing data about this area.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgements

We gratefully acknowledge the volunteers involved in this study.

REFERENCES

Arazi, H., & Asadi, A. (2011). The effect of aquatic and land plyometric training on strength, sprint, and balance in young basketball players. *Journal of Human Sport and Exercise*, 6, 101-111.

Arazi, H., Asadi, A., Mahdavi, S.A., & Mirfalah Nasiri, S.O. (2014). Cardiovascular responses to plyometric exercise are affected by workload in athletes*. Advances Interventional Cardiology*, 10, 2-6.

Arazi, H., Asadi, A., Moradkhani, M., et al. (2013). Post-plyometric exercise hypotension and heart rate in normotensive individuals: influence of exercise intensity. *Asian Journal of Sports Medicine*, 4, 235-240.

Arazi, H., Asadi, A., Nasehi, M., et al. (2012). Cardiovascular and blood lactate responses to an acute plyometric exercise in female volleyball and handball players. *Sport Sciences for Healt*h, 8, 23-29.

Arazi, H., Coetzee, B., & Asadi, A. (2012). Comparative effect of land and aquatic based plyometric training on the jumping ability and agility of young basketball players. *South African Journal of Research in Sport, Physical Education and Recreation*, 34(1), 1-14.

Armstrong, R.B., Oglivie, R.W., & Schwane, J.A. (1983). Eccentric exercise induced injury to rat skeletal muscle. *Journal of Applied Physiology*, 54, 80-93.

Asadi, A. (2014a). Monitoring plyometric exercise intensity using rating of perceived exertion scale. *Physical Activity Review*, 1, 10-15.

Asadi, A. (2014b). Use of rating of perceived exertion for determining plyometric exercises intensity in physically active men. *Sport Sciences fot Health*, 10, 75-78.

Asadi, A., & Arazi, H. (2012). Effects of high-intensity plyometric training on dynamic balance, agility, vertical jump and sprint performance in young male basketball players. *Journal of Sport and Health Research, 4, 34-44.*

Asp, S., Daugaard, J.R., Kristiansen, S., et al. (1998). Exercise metabolism in human skeletal muscle exposed to prior eccentric exercise. *Journal of Physiology*, 509, 305-313.

Borg, G. (1998)*. Borg's Perceived Exertion and Pain Scales*. Leeds: Human Kinetics.

Brockett, C.L., Morgan, D.L., Gregory, J.E., et al. (2002). Damage in different types of motor units following repeated active lengthening of the medial gastrocnemius muscle of the cat. *Journal of Applied Physiology*, 92, 1104-1110.

Brown, G.A., Ray, M.W., Abbey, B.M., et al. (2010). Oxygen consumption, heart rate, and blood lactate responses to an acute bout of plyometric depth jumps in college-aged men and women. *Journal of Strength and Conditioning Research*, 24, 2475-2482.

Byrne, C., & Eston, R.G. (2002). The effects of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. *Journal of Sports Sciences*, 20, 417-425.

Carlson, K., Magnusen, M., & Walters, P. (2009). Effect of various training modalities on vertical jump. *Research in Sports Medicine*, 17, 84-94.

Chatzinikolaou, A., Fatouros, I., Gourgoulis, V., et al. (2010). Time course of changes in performance and inflammatory responses after acute plyometric exercise. *Journal of Strength and Conditioning Research*, 24, 1389-1398.

Chu, D, A. (1998). *Jumping Into Plyometrics*. Champaign, IL: Human Kinetics.

Clarkson, P.M., & Sayers, S. (1995). Etiology of exercise induced muscle damage. *Journal of Applied Physiology*, 24, 234-248.

Devita, P., & Skelly, W.A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise*, 24, 108-115.

Ebben, W.P., Simenz, C., & Jensen, R.L. (2008). Evaluation of plyometric intensity using electromyography. *Journal of Strength and Conditioning Research*, 22, 861-868.

Enoka, R.M. (1996). Eccentric actions require unique activation strategies by the nervous system. *Journal of Applied Physiology*, 81, 2339-2346.

Eston, R.G., & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *Journal of Sports Sciences*, 17, 231-238.

Fridén, J., & Lieber, R.L. (1992). Structural and mechanical basis of exercise-induced muscle injury. *Medicine and Science in Sports and Exercise*, 24, 521-530.

Halliwill, J.R., Taylor, J.A., & Eckberg, D.L. (1996). Impaired sympathetic vascular regulation in humans after acute dynamic exercise. *Journal of Physiology*, 495, 279-288.

Ingalls, C.P., Warren, G.L., Williams, J.H., et al. (1999). E-C coupling failure in mouse EDL muscle after in vivo eccentric contractions. *Journal of Applied Physiology*, 85, 58-67.

Jamurtas, A.Z., Fatouros, A., Buckenmeyer, P., et al. (2000). Effects of plyometric exercise on muscle soreness and plasma creatine kinase and its comparison with eccentric and concentric exercise. *Journal of Strength and Conditioning Research*, 14, 68-71.

MacDonald, J.R., MacDougall, J.D., Interisano, S.A., et al. (1999). Hypotension following mild bouts of resistance exercise and submaximal dynamic exercise. *European Journal of Applied Physiology Occupational Physiology*, 79, 148-154.

Maughan, R., Gleeson, M., & Greenhaff, P.L. (1997). *Biochemistry of Exercise and Training*. New York: Oxford University Press,

Pescatello, L.S., Franklin, B.A., Fagard, R., et al. (2004). American College of Sports Medicine position stand. Exercise and hypertension. *Medicine and Science in Sports and Exercise*, 36, 533-553.

Tofas, T., Jumurtas, A.Z., Fatouros, I., et al. (2008). Plyometric exercise increases serum indices of muscle damage and collagen breakdown. *Journal of Strength and Conditioning Research*, 22, 490-496.

Twist, C., & Eston, R.G. (2005). The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. *European Journal of Applied Physiology*, 94, 652-658.

Semark, A., Noakes, T.D., St Clair Gibson, A., et al. (1999). The effect of a prophylactic dose of flurbiprofen on muscle soreness and sprinting performance in trained subjects. *Journal of Sports Sciences*, 17, 197-203.Victor, R.G., Bertocci, L.A., & Pryor, S.L. (1988). Sympathetic discharge is coupled to muscle cell pH during exercise in humans. *Journal of Clinical Investigation*, 82, 1301-1305.

Warren, G.L., Lowe, D.A., Hayes, D.A., et al. (1993). Excitation failure in eccentric contraction-induced injury of mouse soleus muscle. *Journal of Applied Physiology*, 68, 487-490.

H. Arazi
University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, P.O. Box: 41635-1438, Rasht, Iran
e-mail: hamidarazi@yahoo.com