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Article *in* The Journal of Strength and Conditioning Research · December 2012

DOI: 10.1519/JSC.0b013e318280c9e9 · Source: PubMed

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Effects of Plyometric Training Volume and Training Surface on Explosive Strength

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Abstract

Campillo, RR, Andrade, DC, and Izquierdo, M. Effects of plyometric training volume and training surface on explosive strength. *J Strength Cond Res* 27(10): 2714–2722, 2013–The purpose of this study is to examine the effects of different volume and training surfaces during a short-term plyometric training program on neuromuscular performance. Twenty-nine subjects were randomly assigned to 4 groups: control group (CG, $n = 5$), moderate volume group (MVG, $n = 9$, 780 jumps), moderate volume hard surface group (MVG_{HS}, $n = 8$, 780 jumps), and high volume group (HVG, $n = 7$, 1,560 jumps). A series of tests were performed by the subjects before and after 7 weeks of plyometric training. These tests were measurement of maximum strength (5 maximum repetitions [5RMs]), drop jumps (DJs) of varying heights (20, 40, and 60 cm), squat and countermovement jumps (SJ and CMJ, respectively), timed 20-m sprint, agility, body weight, and height. The results of the present study suggest that high training volume leads to a significant increase in explosive performance that requires fast stretch-shortening cycle (SSC) actions (such as DJ and sprint) in comparison to what is observed after a moderate training volume regimen. Second, when plyometric training is performed on a hard training surface (high-impact reaction force), a moderate training volume induces optimal stimulus to increase explosive performance requiring fast SSC actions (e.g., DJ), maximal dynamic strength enhancement, and higher training efficiency. Thus, a finding of interest in the study was that after 7 weeks of plyometric training, performance enhancement in maximal strength and in actions requiring fast SSC (such as DJ and sprint) were dependent on the volume of training and the surface on which it was performed. This must be taken into account when using plyometric training on different surfaces.

Key Words reactive strength, jump height, drop jump

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27(10)/2714–2722

Journal of Strength and Conditioning Research

Introduction

Ability to produce muscle power output by the lower extremity muscles is a relevant performance issue in many sports activities (21). Plyometric exercises are commonly used to increase explosive power, by means of the stretch-shortening cycle (SSC) (28). Plyometric training is highly effective, with the advantage of requiring reduced physical space, time, and equipment to complete the training sessions (9). Several previous studies have been inconclusive in establishing an optimized plyometric training design (i.e., frequency, volume, and height of landing) to promote muscle power enhancement (1–3,7,8).

Drop jumps (DJs) are common exercises during plyometric training. A DJ implies a sudden eccentric muscle action, which activates a reflex contraction and higher muscle activity (1). A DJ also implies a rapid coupling between an eccentric and concentric muscle action, commonly referred as SSC (14). An SSC could be fast (i.e., DJ) or slow (i.e., counter movement jump [CMJ]), depending on the contact time before the jump (4), implying different biomechanical and physiological effects (3). Therefore, it may be suggested that depending on the type of SSC stimulus performed, one may induce different plyometric training adaptations.

Although commonly accepted as an effective training method, previous studies have not established optimum plyometric training design (i.e., volume) for explosive strength enhancement (1,3,7). Also, the environment (i.e., landing surface) where plyometric training took place had been poorly studied. The type of training surface during plyometric workout may affect the type of SSC being performed (fast vs. slow), implying different biomechanical and physiological effects (3), and possible different long-term adaptations. Therefore, it may be suggested that depending on the type of SSC stimulus, one may devise different plyometric training adaptations. However, to the best of the authors' knowledge, a limited amount of scientific literature has controlled this determinant variable (17,31). Stemm and Jacobson (31) trained a group of athletes with the same plyometric program but with different training surfaces (water vs. sports mat). Both groups improved performance, but no differences between regimens were observed, and the subjects were not assigned to their groups randomly.

In another study, Impellizzeri et al. (17) examined the effect of 4 weeks of plyometric training in a soccer team that trained on grass vs. sand surfaces. Both groups obtained similar improvements in squat jump (SJ), but the grass training group obtained a significant increase in CMJ and SJ/CMJ reactive index vs. the sand trained group. On the other hand, the sand trained group experienced less muscle pain. Unfortunately, none of these studies quantified the hardness of the training surfaces with their respective restitution coefficient. This is determined by the separation velocity and the approximation velocity of 2 objects before and after they collide and is expressed in absolute values (22). Thus, further research is needed to clarify the effect of plyometric training factors such as volume and training surface on performance adaptations. The purpose of this study was to determine the effects of 2 different plyometric training volumes (moderate vs. high), and training surfaces (hard vs. soft) on motor performance characteristics of untrained adolescent males. It was hypothesized that motor performance (agility, sprint, strength, and jump) will adapt differently according to the training surface and volume used during 7 weeks of plyometric training.

Methods

Experimental Approach to the Problem

This study was designed to address the question of how a short-term plyometric training program of moderate frequency (2 sessions per week), using moderate/high volume and/or hard/soft surface, affects maximal and explosive strength, agility, and running speed performance. To do this, we compared the effects of 7 weeks of plyometric treatment in 4 groups of subjects. Some initial tests were executed to establish a baseline. The initial tests were completed in 4 days (Monday, Tuesday, Thursday, and Friday). After the initial measurements, subjects were randomly assigned to 1 of 4 groups: control (CG, $n = 5$), moderate volume (MVG, $n = 9$, 60 jumps per session, for a total of 780 jumps), moderate volume hard surface (MVG_{HS}, $n = 8$, 60 jumps per session, for a total of 780 jumps), and high volume (HVG, $n = 7$, 120 jumps per session, for a total of 1,560 jumps). The control group did not train. Our study design (4 groups) permit us the comparison between HVG, MVG (both trained over soft surface), and a control group, to determine the effect of the independent variable volume, related to the first of our research questions. On the other hand, the comparison between MVG and MVG_{HS} (similar training volumes but on different coefficient restitution surfaces), as well as a control group, let us to determine the effect of the independent variable surface, related to the second of our research questions. Unfortunately, a fifth research group (high volume and hard surface) was not incorporated because of the high volume of plyometric training, over hard training surface, may have increased the injury risk on the subjects (6). Thus, ethical issues preclude us to incorporate a fifth group. The training groups used the same intensity during exercises. Before beginning the training period, the subjects were instructed to properly execute all the exercises to be done during this period. The training protocol included DJ from 3 different heights (20, 40, and 60 cm). All training sessions were supervised. The subjects were instructed to maintain their dietary habits for the whole duration of the study. Also, subjects were instructed to use the same sport shoes during the pre- and postintervention testing.

Subjects from the MVG_{HS} used a hard (gymnasium floor) surface, whereas subjects from the HVG and MVG used a soft (athletic mat over gymnasium floor) surface to complete the plyometric training. The hardness of the training surfaces was quantified by means of a restitution coefficient. The coefficient of restitution was determined by using a high-speed (300 frames per second) camera (Samsung, model sc-mx20c HD). This coefficient is commonly used to determine some physical characteristics for sports balls and other sports elements (i.e., baseball bat) (26). In our investigation, the restitution coefficient of a tennis ball (0.73) was used as a baseline to assess the impact of this type of ball on the athletic mat and gymnasium floor. The differences observed in the restitution coefficient where attributed to the surface characteristics of the mat and gymnasium floor (22). The athletic mat had a restitution coefficient of 0.53, and the gymnasium floor had a restitution coefficient of 0.8.

Subjects

This study involved a group of high school adolescent males (16.89 ± 0.85 years of age). None of the subjects had any background in regular strength training or competitive sports that involved any of the training methods used in the investigation. Because plyometric exercises may induce important adaptations, requiring reduced physical space, time, and equipment, they are commonly used in untrained subjects (i.e., during physical education classes) and during initial phases of children's training and playing approaches. Thus, the interest of the present study was mainly focused on plyometric training effects of different volumes and surfaces (i.e., hard vs. soft) on nontrained boys.

Subjects were reminded during each training session to maintain their usual physical activity habits during the experiment. Exclusion criteria included subjects with (a) potential medical problems or a history of ankle, knee, or back pathology in the 3 months before the study, (b) medical or orthopedic problems that compromised their participation or performance in the study, (c) any lower extremity reconstructive surgery in the past 2 years or unresolved musculoskeletal disorders, and (d) subjects who were taking or had previously taken anabolic steroids, growth hormone, or related performance-enhancement drugs of any kind. However, individuals were not eliminated if they had been taking vitamins, minerals, or related natural supplements (other than creatine monohydrate). Institutional Review Board approval for our study was obtained, and all subjects (and their parents or guardians) were carefully informed about the experiment procedures and about the possible risk and benefits associated with participation in the study, and an appropriate signed informed consent document has been obtained pursuant to law before any of the tests were performed. We comply with the human and animal experimentation policy statement guidelines of the American College of Sports Medicine.

Procedures

All anthropometric measurements were completed between 10:00–11:00 h, whereas performance measurements were completed between 11:00 and 16:00 h. All subjects were instructed to have a good night of sleep before each testing day. Subjects were instructed to avoid drinking or eating at least 2–3 h before measurements. All subjects were motivated to give their maximum effort during performance measurements.

Height was measured using a wall-mounted stadiometer (Butterfly, Shanghai, China) recorded to the nearest 0.5 centimeter. Body mass was measured to the nearest 0.1 kg using a digital scale (BC-554 Ironman Body Composition Monitor, Tanita, IL, USA). The body mass index (BMI) was determined by dividing body mass by the square height of the subject (kilograms per square meters). The subjects were carefully familiarized with the test procedures during several submaximal and maximal actions a few days before the performance measurements were taken (4 learning sessions during 2 weeks). The subjects also completed several explosive type actions to become familiar with the exercises used during training. In addition, several warm-up muscle actions were performed before the actual maximal and explosive test actions. All tests were carried out before and after 7 weeks of plyometric training. The study was completed during winter. The performance tests were completed in 4 days. On day 1, the following tests were completed: height, body mass, SJ, and CMJ for maximal vertical distance (centimeters), DJ (from 20, 40, and 60 cm) for reactive strength (centimeters per milliseconds). On day 2, the 20-m sprint test was carried out; on day 3, the 5 repetition maximum (5RM) test was completed, and on day 4, the Illinois agility test (23) was completed. Ten minutes of standard warm-up (5 minutes of submaximal running with several displacements, stretching exercises for 5 minutes, and 2 submaximal jump exercises of 20 vertical jumps and 10 longitudinal jumps) were executed before each testing day.

Maximal Dynamic Strength (5 RM). A parallel squat test was selected to provide data on maximal dynamic strength of the lower extremity muscles. Maximal strength was assessed using concentric-eccentric 5RM parallel squat action. Parallel squat tests were completed using free weights, with the subject assuming an initial erect position with the bar behind the shoulders. Then, the subjects lowered the bar until the upper portion of the thighs was parallel with the floor (determined visually by the investigators). Finally, the subject performed a concentric leg extension (as fast as possible) to reach the full extension of 180 degrees against the resistance determined by the weight. This action was repeated 5 times, with the maximum weight possible. Warm-up consisted of a set of 10 repetitions at loads of 40–60% of the perceived maximum. After 1 minute of rest and mild stretching, subjects performed a second set of 3–5 repetitions at loads of 60–80% of the perceived maximum. Thereafter, the subjects had a maximum of 5 separate attempts to find their 5RM. The last acceptable 5 consecutive repetitions with highest possible load (kilograms) were determined as 5RM. The rest period between the actions was always between 3 and 5 minutes.

Explosive Strength. The subjects performed DJ from a 20-, 40-, and 60-cm high platform, using an electronic contact mat system (Globus Tester, Codogne, Italy) with a precision of 0.01 m. The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimal contact time, to maximize jump reactive strength. The subjects were again instructed to leave the platform with knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test. Four basic techniques were stressed: (a) correct posture (i.e., spine erect and shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (b) jumping straight up with no excessive side-to-side or forward-backward movement; (c) soft landing including toe-to-toe heel rocking and bent knees; and (d) instant recoil for the concentric part of the jump. Phrases such as "on your toes," "straight as a stick," "light as a feather," and "recoil like a spring" were used as verbal and visualization cues during the DJ. The instruction given to the subjects were "jump as high as you can, with minimum ground contact time." Three repetitions were executed from each height, with 10–15 seconds between repetitions. The best performance trial was used for the subsequent statistical analysis. Trials with contact times over 250 miliseconds were not recorded. The intraclass correlation coefficient was 0.97 (0.96–0.98) for 20-cm DJ, 0.97 (0.96–0.98) for 40-cm DJ, and 0.97 (0.96–0.98) for 60-cm DJ.

Squat Jump. An SJ was also used to assess maximal vertical jump height performance. The SJ test was performed using an electronic contact mat system (Globus Tester) with a precision of 0.01 m. Jump height was determined using an acknowledged flight-time calculation (5,6). During SJ, the subject was instructed to rest his hands on his hips, foot, and shoulders wide apart, adopt a flexed knee position (approximate 90 degrees) during 3 seconds (25), and followed by a maximal effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees after landing. Three trials were completed, with 10–15 seconds of

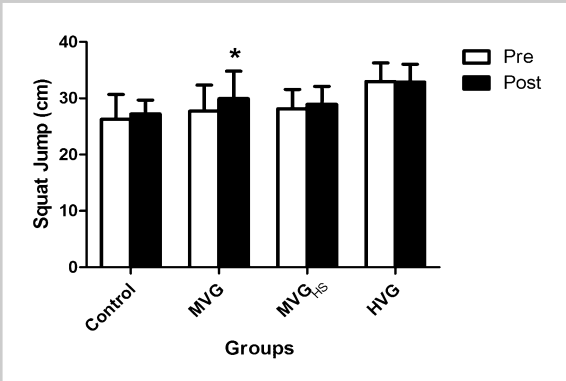

Figure 1. Squat jump (SJ) performance (centimeters) in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

rest between them, and the best performance trial was used for the subsequent statistical analysis.

Countermovement Jump. A CMJ was used to assess maximal jump height performance requiring slow SSC action. The CMJ test was performed using an electronic contact mat system (Globus Tester) with a precision of 0.01 m. Jump height was determined using an acknowledged flight-time calculation (5). During CMJ, the subject was instructed to rest his hands on his hips, foot, and shoulders wide apart; subjects performed a downward movement (no restriction was imposed over the knee angle achieved (30)) followed by a maximal effort vertical jump. All subjects were instructed to land in an upright position and to bend their knees after landing. Three trials were completed, with 10–15 seconds of rest between them, and the best performance trial was used for the subsequent statistical analysis.

The 20-m Sprint Time. Sprint times were recorded for 20-m distances. The 20-m sprint test was conducted indoors on a wooden running surface. For all sprint tests, the subject started using a crouch start and commenced sprinting with a random sonorous sound. Infrared beams were positioned at the sprint distance, 1-m over the floor, to be measured with photoelectric cell (Globus Tester). Subjects were given 2 practice trials performed at half speed after a thorough warm-up to familiarize them with the timing device. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between 20-m trials. Times were recorded to the nearest 0.01 second.

Agility. Agility times were recorded for the Illinois agility test. The test was used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles (29). The Illinois agility test is set up with 4 cones forming the agility area (10-m long × 5-m wide). A cone was placed at each point (a) to mark the start, (b and c) to mark the turn spots, and (d) to mark the finish. Another 4 cones were placed in the center of the testing area, 3.3 m from each other. The test was conducted indoors on a wooden running surface. For all agility tests, the subject starts on the floor, face down, and begins with a random sonorous sound. The subjects must complete, as fast as possible, the agility circuit. Infrared beams were positioned at the finish point, 1-m over the floor, to take measurements with a photoelectric cell

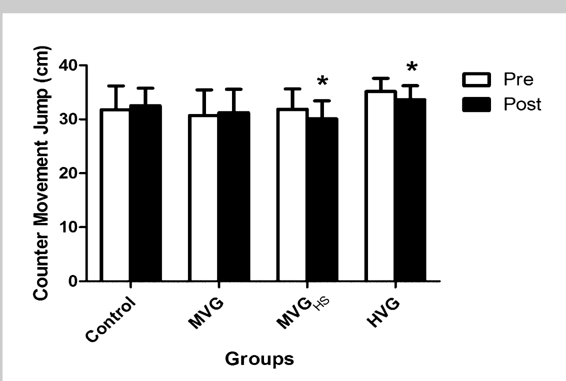

Figure 2. Counter movement jump performance (centimeters) in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

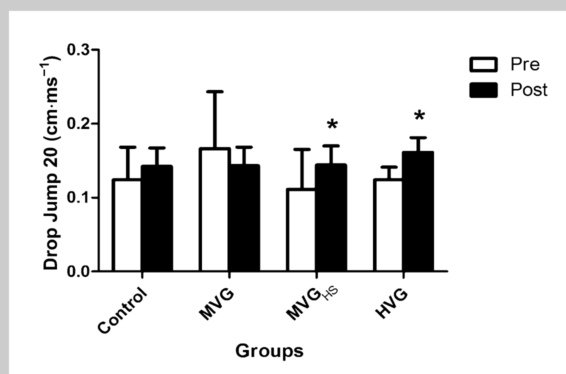

Figure 3. Drop jump performance (centimeters per millisecond–reactive strength) from 20-cm drop height in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding pre value ($P < 0.05$).

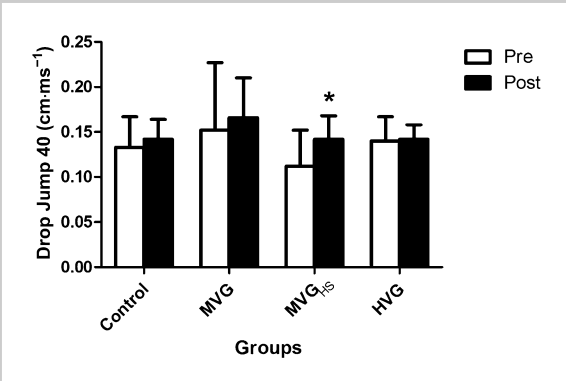

Figure 4. Drop jump (DJ) performance (centimeters per millisecond–reactive strength) from 40-cm drop height in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

(Globus Tester). Subjects were given 2 practice trials performed at half speed after a thorough warm-up to familiarize them with the circuit and timing device. Two trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between agility trials. Times were reported to the nearest 0.01 second (23).

Treatment

The plyometric training took place 2 days per week (with at least 48 hours of rest between sessions) for the plyometric training groups, during 7 weeks of treatment. Each session lasted 30–45 minutes. Ten minutes of standard warm-up (i.e., 5 minutes of submaximal running and several displacements, stretching exercises for 5 minutes, 20 submaximal vertical jumps, and 10 submaximal longitudinal jumps) was used before the main part of the training session. The plyometric exercises consisted of DJ (bounce drop jumps), with a total of 60 DJs per session (2 series of 10 jumps from a 20-cm box, 2 series of 10 jumps from a 40-cm box, and 2 series of jumps from a 60-cm box) for the MVG and MVG_{HS} groups, and a total of 120 DJs per session (4 series of 10 jumps from a 20-cm box, 4 series of 10 jumps from a 40-cm box, and 4 series of jumps from a 60-cm box) for the HVG group. The rest period between repetitions was approximately of 5 seconds and between series was 1.5 minutes. The control group did not perform any training intervention. This group underwent the same testing protocols as the other groups.

The training was performed on a wood gymnasium floor with a restitution coefficient of 0.8 (MVG_{HS}) or on a 3-cm thick athletic mat (6) with a restitution coefficient of 0.5 (MVG and HVG). The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion, ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimum contact time in every jump. These instructions were intended to maximize reactive strength. A researcher was always present during training sessions, motivating subjects to give their maximum effort in each jump.

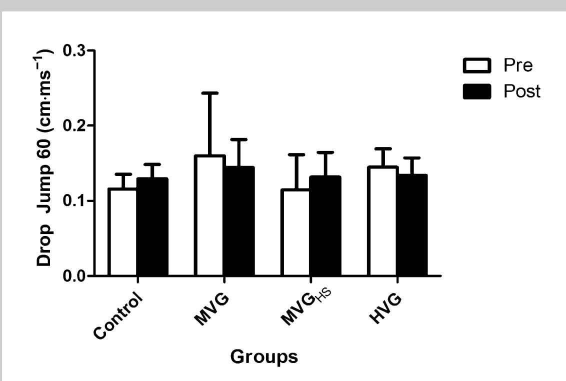

Figure 5. Drop jump performance (centimeters per millisecond–reactive strength) from 60-cm drop height in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

Statistical Analyses

Descriptive statistics (mean ± *SD*) for the different variables were calculated. Pre- and postvalues for the dependent variables were analyzed to determine if the distributions were normal using the Shapiro-Wilk Normality test. To determine the effect of different plyometric training volumes and surfaces on explosive strength adaptations, a 2-way variance analysis with repeated measurements (4 groups × 2 times) was applied. When a significant *F* value was achieved across time or between groups, Fisher's least significant difference post hoc procedures were performed to locate the pairwise differences between the means. The α level was set at $P \leq 0.05$ for statistical significance. All statistical calculations were performed using STATISTICA statistical package (Version 8.0; StatSoft, Inc, Tulsa, OK, USA).

Results

At baseline, no significant differences between the experimental groups were observed in any anthropometric and performance variables. After training, no significant changes were observed in the control group. During the 7 weeks of plyometric training, no statistically significant changes were observed in the height, body mass, or BMI in the experimental groups.

After 7 weeks of treatment, a significant increase ($p < 0.05$) was observed in SJ in the MVG group (prevalue = 27.7 ± 4.7 cm; postvalue = 30 ± 4.9 cm) (Figure 1), whereas a significant reduction ($p < 0.05$) in CMJ performance was observed in the

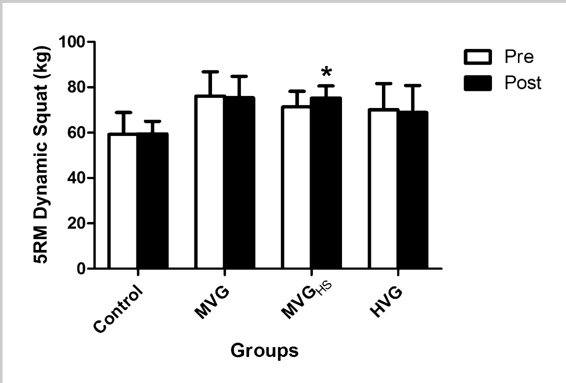

Figure 6. Maximal strength (5-maximum-repetition [5RM] dynamic squat) performance (kilograms) in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescent males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

MVG_{HS} (prevalue = 31.9 ± 3.8 cm; postvalue = 30.1 ± 3.3 cm) and HVG (prevalue = 35.1 ± 2.4 cm; postvalue = 33.6 ± 2.6 cm) groups (Figure 2).

After training, a similarly significant increase ($p < 0.05$) in 20-cm DJ was observed in MVG_{HS} (prevalue = 0.111 ± 0.05 $cm \cdot ms^{-1}$; postvalue = 0.144 ± 0.03 $cm \cdot ms^{-1}$) and HVG (prevalue = 0.124 ± 0.02 $cm \cdot ms^{-1}$; postvalue = 0.161 ± 0.02 $cm \cdot ms^{-1}$) (Figure 3), whereas the training efficiency was significantly higher in the MVG_{HS} (0.038% per jump) compared with the HVG (0.019% per jump) group. In DJ 40-cm, only MVG_{HS} obtained a significant increase ($p < 0.05$) in performance (prevalue = 0.112 ± 0.04 $cm \cdot ms^{-1}$; postvalue = 0.142 ± 0.03 $cm \cdot ms^{-1}$) (Figure 4). No significant changes were observed in DJ 60-cm in any experimental group (Figure 5).

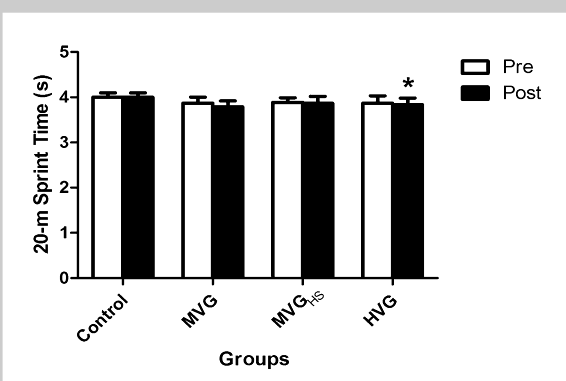

Figure 7. The 20-m sprint performance (seconds) in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescents males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

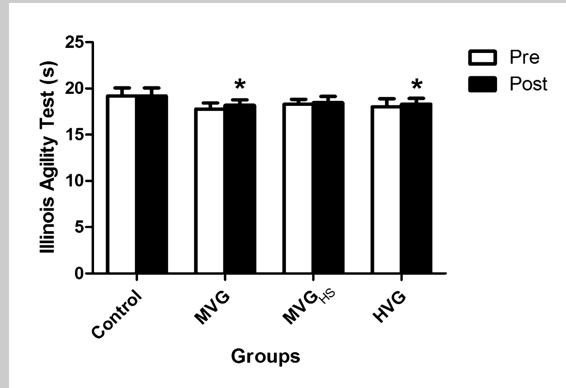

Figure 8. Agility performance (seconds) in experimental groups before (white columns) and after (dark columns) 7 weeks of plyometric training in adolescents males. MVG ($n = 9$): moderate volume group (120 jumps per week); MVG_{HS} ($n = 8$): moderate volume group (120 jumps per week), using hard landing surface; HVG ($n = 7$): high volume group (240 jumps per week). *Denotes significant difference with the corresponding prevalue ($P < 0.05$).

After 7 weeks of training, MVG_{HS} had a significant ($p < 0.05$) increase in maximal dynamic strength (prevalue = 71.3 ± 6.9 kg; postvalue = 75.2 ± 5.4 kg), whereas no significant changes were observed in MVG (prevalue = 76 ± 10.8 kg; postvalue = 75.4 ± 9.4 kg), and HVG (prevalue = 70 ± 11.7 kg; postvalue = 68.8 ± 12 kg) (Figure 6).

After training, HVG had a significant ($p < 0.05$) reduction in sprint time (prevalue = 3.87 ± 0.16 seconds; postvalue = 3.84 ± 0.14 seconds) (Figure 7), whereas no significant changes were observed in MVG (prevalue = 3.87 ± 0.13 seconds; postvalue = 3.79 ± 0.13 seconds) and MVG_{HS} (prevalue = 3.89 ± 0.10 seconds; postvalue = 3.87 ± 0.15 seconds).

MVG and HVG exhibited a significant reduction ($p < 0.05$) in agility performance (prevalue = 17.8 ± 0.7 seconds and postvalue = 18.2 ± 0.6 seconds; prevalue = 18 ± 0.9 seconds and postvalue = 18.3 ± 0.6 seconds, respectively) after 7 weeks of plyometric training, whereas no significant changes were observed in MVG_{HS} (prevalue = 18.3 ± 0.5 seconds; postvalue = 18.5 ± 0.7 seconds) (Figure 8).

Discussion

The main findings of this study were that high training volume led to a significant increase in explosive performance requiring fast SSC actions (DJ and sprint) compared with what was observed after a moderate training volume. Second, when plyometric training was performed on a hard training surface (high impact reaction force), a moderate training volume induced optimal stimulus to increase explosive performance requiring fast SSC actions (DJ), maximal dynamic strength, and training efficiency. Thus, an interesting finding of the present study was that after 7 weeks of plyometric training, performance enhancements in actions requiring maximal strength and fast SSC (DJ and sprint) were dependent on the training surface and training volume.

In accord with previous studies, jump training involving DJ exercises effectively enhanced motor performance (16). Moreover, plyometric training protocols in adolescent males (similar to those applied in the study) have shown to be effective in inducing an increase in motor performance (32). However, in contrast with a previous study (6), our results indicate that high vs. moderate plyometric training volume of DJ (1,560 vs. 780 jumps in 7 weeks) led to different training-induced explosive performance gains. The MVG experienced a significant increase in SJ (18%), whereas the HVG exhibited a significant increase in 20-cm DJ (28.8%) and a significant reduction in sprint time (−0.8%). The difference between our results and those of the previous study might be explained by the differences in the subject selection criteria. In the study of de Villarreal et al. (6), active physical education students took part in their study, whereas in our study, the subjects where non-trained adolescents. It is worth noting the significant reduction in CMJ performance exhibited by the HVG (−4.4%), whereas the MVG did not change their performance in this test. It is possible that training with high volume and low specificity (i.e., a CMJ implicates a slow SSC muscle action, whereas a bounce DJ implicates a fast SSC muscle action) might influence this result.

Our results also show that the hardness of the training surface used during plyometric training has an effect on training adaptations. A novel aspect of this study was to use 2 different training surfaces (gymnasium floor vs. athletic mat) for completing 7 weeks of plyometric training and to examine their impact on jump, strength, sprint, and agility performance. Moreover, to the best of the author's knowledge, quantification on the hardness of the training surfaces for plyometric training by means of the coefficient of restitution has not been reported before in the literature. This unique approach may establish a precedent for future plyometric training studies. Before the intervention, MVG and MVG_{HS} exhibit similar anthropometric and performance characteristics. As mentioned before, after the intervention, the only favorable performance change exhibited by the MVG was a significant increase in SJ performance (18%). On the other hand, the MVG_{HS} exhibited a significant increase in explosive reactive strength during 20-cm DJ (29.7%) and 40-cm DJ (26.8%). The MVG_{HS} also exhibited increased performance in maximal dynamic strength (5.4%), which may be related to the increased ground impact forces encountered during landing in a hard surface. Reduction in CMJ performance by the MVG_{HS} was significant (−5.6%) and similar to what was observed in HVG, whereas the MVG did not change this variable. On the other hand, a significant reduction in agility performance was observed in the MVG (−2.4%) but not in the MVG_{HS}. Our results contrast with those reported by Stemm and Jacobson (31) that used 2 different plyometric training surface (water vs. athletic mat) for 6 weeks. They observed no difference in performance change between the training surfaces. On the other hand, our results agree to those reported by Impellizzeri et al. (17), in which a group of soccer players trained on 2 different surfaces (grass and sand) and reported that the soccer players trained in sand obtained a notable increase in SJ performance vs. players trained on grass.

Another interesting finding was that when a reduced volume of plyometric training is combined with a relatively hard training surface, it may represent an optimal stimulus to induce significant neuromuscular adaptations. So, the training environment (i.e., surface hardness) can be modified to increase the training efficiency of plyometric exercises. In this regard, although the MVG_{HS} and HVG show a significant and almost identical increase in explosive reactive strength during training, (29.7 and 29.8%, respectively), the training efficiency was superior in the MVG_{HS} (0.038% per jump) compared with HVG (0.019% per jump). Previous studies corroborate that a larger volume may result in less training efficiency (6,11,12). It seems that when an optimal training load is achieved, further increases in volume do not offer additional benefits and may even negatively affect performance (12,13,27). The stretch loads, storage of elastic energy, precontraction activation state, and activation of the stretch reflex can be influenced by the type of surface used during plyometric training (3). The characteristics of a soft landing surface during plyometric training may potentially reduce the mechanical load on the musculoskeletal system and hence the training effect on the efficiency of the muscle-tendon complex (18). This agrees with our results, where a significant effect of training surface was found in some jump characteristics related to the efficiency of the SSC. So, when a hard surface is used during plyometric training, a low optimal volume may be indicated. On the other hand, the use of a soft landing surface during jumping may require a more intense concentric push-off phase, probably to compensate for a lower reuse of the stored elastic energy caused by the soft surface absorption (24). This may help explain why the MVG exhibited an increase in SJ performance, but still it remains unclear why the HVG training stimulus do not represent an optimal stimulus to promote similar training adaptations.

On the other hand, a relatively high volume of plyometric training may be important to induce enhancement in sprint performance when a soft landing surface is used. In the present study, a high volume of training induced a significant reduction in sprint time (−0.8%). Similar reduction has been reported previously (15). It has been speculated that the contact time during DJ exercises must be less than 200 miliseconds to induce a specific stimuli in relation with the contact time encounter in an acceleration sprint (i.e., 20 m). In the present investigation, the trained subjects were instructed to execute DJ with emphasis on minimizing contact time and maximizing jump height. Although not controlled during training sessions, the contact time of subjects during basal evaluation (the same instruction and motivation was given during evaluation and training sessions) of DJ executed from 20, 40, and 60 cm was almost always under 200 miliseconds. So, the specificity of the exercise (32), accompanied with a high number of repetitions, may be important to induce sprint performance enhancement, maybe by means of motor learning adaptations (20). It is important to notice that the only training group that exhibited an increase in sprint performance was the HVG. So, the volume of training, not the type of surface, affected the improvement in sprint performance.

In conclusion, during 7 weeks of plyometric training, using only DJ exercises in nontrained adolescent males, only high plyometric training volume (240 jumps per week) induced a significant increase in sprint performance. Also, only a hard plyometric training surface (restitution coefficient 0.8) induced an increase in maximal dynamic strength performance. Although both, a high plyometric training volume and a hard training surface had an effect on DJ performance, only the hard training surface induced an increase in fast SSC muscle action after high drop jump height and proves to be highly efficient to induce performance adaptations (0.038% per jump). On the other hand, a higher volume or a harder training surface may limit adaptations in maximal jump height depending on slow SSC (i.e., CMJ) or pure concentric strength (i.e., SJ) when fast SSC muscle actions are used during training.

Practical Applications

Our results indicate that different plyometric training volumes and surfaces are associated with different explosive strength adaptations. Concretely, our data indicate that a moderate plyometric training volume (i.e., 60 jumps per session or 120 jumps per week) would not induce an increase in sprint performance, instead, a high plyometric training volume (i.e., 120 jumps per session or 240 jumps per week) would be necessary to induce an increase in acceleration sprint (i.e., 20 m). Therefore, a high volume of fast SSC muscle actions during training may be required to induce an increase in acceleration sprint.

Our data also indicate that when moderate volume is used during plyometric training, a hard training surface would be needed if adaptations in fast SSC muscle actions, or reactive strength, are an important objective of training.

Finally, the present data also suggest that, compared to a high plyometric training volume completed on a soft surface (i.e., 3-cm thick athletic mat), using a moderate plyometric training volume on a hard surface (i.e., wood gymnasium floor) would double the efficiency of adaptations in reactive strength. In others words, a high volume of training would not be necessary to induce reactive strength adaptations when a hard landing surface is used. These results do not support the notion of "the more, the better." So, using a harder surface, and lower plyometric training volume, significant (and time saving) explosive strength adaptations could be achieved.

Concern has been expressed by some researchers with regard to the training surface used during plyometric training because of its (speculated) high harm/injury index. To the best of the author's knowledge, when adequate controlled plyometric training intervention had been applied, no important injuries had been reported. In fact, plyometric training had been advocated as a preventive injury strategy (10,19) and even as a rehabilitation tool (14). It is important to notice that in the present investigation, no injuries were reported. More so, subjects reported little subjective muscle pain after the training sessions (data not shown), even when a hard training surface was used. So, a hard plyometric training surface can be preferred if an increase in maximal dynamic strength is needed.

An important practical aspect of our results is that by controlling the training surface intensity, specific neuromuscular adaptations can be induced. For example, plyometric training, with a coefficient of restitution intensity of 0.8, induced a significant increase in maximal dynamic strength, but training with a coefficient of restitution intensity of 0.53 would not be an adequate stimulus to induce increase in maximal dynamic strength. Thus, minimum threshold intensity may be required to induce neuromuscular adaptations after plyometric training.

Also, our data indicates that when high-intensity fast SSC muscle actions (i.e., DJ) are performed during plyometric training, due to their low specificity with respect to a low-intensity slow SSC muscle action (i.e., CMJ), a high volume of plyometric training, and/or a hard training surface, may negatively impact the performance during the latter type of muscle activity. Optimal design of plyometric training programs should take our results in to consideration.

Acknowledgments

The authors have no conflicts of interest to declare and no professional relationships with companies or manufacturers that may benefit from the results of this study. The results of this study do not constitute endorsement of the product by the authors of the National Strength and Conditioning Association. The authors have no funding to disclose for this work from any of the following organizations: National Institutes of Health, Welcome Trust, Howard Hughes Medical Institute, and other(s).

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