

Effects of Plyometric Training Program on Speed and Explosive Strength of Lower Limbs in Young Athletes

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Abstract:

Plyometric training can improve jumping performance and running velocity in both pubertal and prepubertal populations. It has been shown that jumps of various kinds can also precede the specific session of one's sport, with clear improvements on the various performances of jumping or running. However, it is unclear whether the resulting improvement in explosive performance is because of introduction of a new training regimen or whether it merely reflected the response to an additional training load. Thus, this randomized controlled trial aimed to examine the effect of a combined plyometric and traditional athletics training on speed and explosive strength of the lower limbs. Participant (22 boys, 13-14 yr) were randomly assigned to an 8-wk experimental group (EG, n = 10) who performed plyometric training or a control group (CG, n = 12) who continued their traditional training. The EG performed twice weekly sessions of plyometrics (15 min.), in addition to their standard training without increasing the total training time (90 min.). At baseline and after training all participants were tested on the 20-m sprint (time) and Squat Jump (power, velocity, force and height). The EG group showed significantly ($p < 0.05$) improvement than CG in the 20-m sprint time (-0.1 vs. 0.1 sec) and Squat Jump (160.8 vs. -31.9 W; 0.3 vs. -0.2 m·s⁻¹; 45.3 vs. -6.3 N; 10.9 vs. -2.2 cm) following training. Eight weeks of plyometric training added to the standard program of athletics was highly likely to improve the lower limbs speed and explosive strength in young athletes. Our findings highlight the potential value of combined training methods in a conditioning program aimed at maximizing power performance in youth.

Key Words: power; adolescent; youth; combined training; stretch-shortening cycle; vertical jump.

Introduction

Plyometrics have been used for many decades in the Russian and eastern European training of track and field athletes (Chu, 1992). Plyometric training provides the required stimuli and can enhance explosive contractions in both pubertal (Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jaric, 2001) and prepubertal (Litwiler & Hamm, 1973) populations. Such a regimen is natural to many sports, with its emphasis on jumping, throwing, hopping, and skipping, and it is particularly appropriate where there is a need to develop explosive movements and vertical jumping ability, as in athletics. The stretching forces that occur during movement, give rise to eccentric muscle contractions with the resulting stored elastic energy, which contributes to an increase in strength in subsequent concentric contractions. This mechanism is known as the Stretch-Shortening Cycle (Komi, 2003; Nicol, Avela, & Komi, 2006). Concerns regarding the safety of plyometric training for young athletes can be minimized by combining a proper technique with a progressive program and close supervision of participants (Kraemer et al., 2002).

Matavulj et al. (2001) found that plyometric training improved jumping performance in teenage basketball players and Kotzamanidis (2006) reported that enhanced jumping performance and running velocity in prepubertal boys. However, plyometric training is not intended to be a stand-alone exercise program (Bompa, 2000; Chu, Faigenbaum, & Falkel, 2006). As previously observed in adults, significantly greater gains in performance may be observed when plyometric training is combined with resistance training (Adams, O'Shea, O'Shea, & Climstein, 1992; Almoslim, 2014; Fatouros et al., 2000). Strength training can increase force availability (Hermassi, Chelly, Fathloun, & Shephard, 2010; Hermassi, Chelly, Tabka, Shephard, & Chamari, 2011), but the high velocity training of plyometrics may improve the rate of force development relative to traditional weight training (Herrero, Izquierdo, Maffiuletti, & Garcia-Lopez, 2006). The strength training program, which included plyometrics, sprinting, and resistance training, was also shown to provide a small but very likely benefit to maximal sprint speed which is an important anaerobic quality required for middle-distance running (Kadono & Enomoto, 2007).

Previous studies of plyometric training in prepubertal and pubertal children (Ingle, Sleep & Tolfrey, 2006) have added the regimen as a supplement to regular sports activities using a multilateral training approach

(Fischetti & Greco, 2017). The minimum duration of a plyometric training must be at least 6 weeks to bring significant benefits and increased performance in young athletes (Faigenbaum et al., 2007; Hammett & Hey, 2003; Lloyd, Oliver, Hughes, & Williams, 2012; Martel, Harmer, Logan, & Parker, 2005; Myer, Ford, Palumbo, & Hewett, 2005). Several studies have shown that plyometric training that uses exercises such as jumps and rebounds is an effective way to improve performance in young athletes (Meylan & Malatesta, 2009; Santos & Janeira, 2011). However, to date there is only limited evidence suggesting that training at specific ages during maturation produces greater adaptations than other ages. Lloyd et al. (2012) demonstrated that there may be periods of accelerated adaptation for the development of the Stretch-Shortening Cycle, between 10-11 and 14-16 years. However, it is unclear whether plyometric training during these periods may elicit greater training adaptations than those that could be achieved through physiological maturation of the young athlete alone.

It has been shown that an average volume of 20-40 jumps of various kinds can also precede the specific session of one's sport, with clear improvements on the various performances of jumping or running (Chelly, Hermassi, Aouadi, & Sherphard., 2014). It has remained unclear whether the resulting improvement in explosive performance was because of introduction of the new training regimen or whether it merely reflected the response to an additional training load. For this reason, our objective in the present study was to determine whether a plyometric training program carried out at the end of the warm-up and before the traditional training session would enhance the explosive movements of male adolescent athletes.

Given existing information on the efficacy of plyometric training (Markovic, Jukic, Milanovic, & Metikos, 2007), we added a plyometric training protocol to the normal regimen for 8 weeks, without increasing the total training time of the experimental group. We hypothesized that two sessions per week of plyometric training, performed for eight weeks at the end of the warm-up and before the traditional training of athletics, can cause a greater increase in the speed and explosive strength of the lower limbs in the experimental group compared to the control group athletes who maintained their standard regimen.

Materials & Methods

Experimental design

To test our hypothesis, adaptations following plyometric plus standard training compared to only standard regimen were assessed using a randomized controlled trial study design with experimenter blinding that included pre- and post-testing at weeks 1 and 8, respectively. This research was designed to obtain baseline data of some physical capacity tests in young athletes, in order to evaluate whether a supervised 8-week plyometric training program can produce improvements. This outcome was defined as statistically significant improvements in the lower limbs speed and explosive strength evaluation tests (i.e., a 20 m-sprint test and a squat jump test).

Participants

Twenty-two healthy boys volunteered to participate in this study. An a priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) with an assumed type I error of 0.05 and a type II error rate of 0.20 (80% statistical power) was calculated for measures of physical capacity and revealed that 8 participants per group would be sufficient to observe medium 'Time x Group' interaction effects. The subjects were recruited by an athletics sport association in Puglia (Italy) in October 2017. The characteristics of the study population are described in Table 1. The exclusion criteria were (a) children with a chronic pediatric disease, (b) children with an orthopedic limitation, and (c) children older than 14 years and younger than 13 years of age. All volunteers were accepted for participation.

Table 1. Baseline physical characteristics. Data are means (\pm SD)

	Control Group (n = 12)	Experimental Group (n = 10)
Age (years)	13.5 (0.5)	13.7 (0.5)
Body Mass (kg)	53.6 (2.2)	53.4 (4.4)
Height (m)	1.67 (0.04)	1.7 (0.04)
BMI (kg·m ⁻²)	19.1 (0.73)	18.6 (1.16)

None of the group differences were significant ($p > 0.05$). BMI = body mass index.

The participants were randomly assigned to two groups: an experimental group (n = 10), which underwent a plyometric training, or a control group (n = 12), which underwent a traditional training alone. For randomization, we used the method of randomly permuted blocks using Research Randomizer, a program published on a publicly accessible official website (www.randomizer.org). All participants and their parents received a complete explanation in advance about the purpose of the experiment, its contents, and safety issues based on the Declaration of Helsinki, and provided their informed consent. The study was conducted from October to November 2017, at the end of the competitive season.

Study procedures

All study procedures were performed on outdoor athletics track with a tartan surface. Initial and final test measurements were made at the same time of day and under the same experimental conditions. Athletes maintained their normal intake of food and fluids, but before testing, they abstained from physical exercise for 1 day, drank no caffeine-containing beverages for 4 hours, and ate no food for 2 hours. Verbal encouragement

ensured maximal effort throughout all tests. Prior to data collection all subjects participated in one introductory session during which time proper form and technique on each physical capacity test were reviewed and practiced. During this session research assistants demonstrated proper testing procedures and participants practiced each test. A standardized battery of warm-up exercises was performed before maximal efforts. On the first test day, subjects performed the Squat Jump, instead anthropometrical assessment and sprint running were undertaken on day 2. The same researcher tested and trained the participants. Pre-testing was performed the week before the training period and post-testing was performed the week after the training period.

Both exercise groups trained twice per week on nonconsecutive days (Tuesday and Thursday) for eight weeks under carefully monitored and controlled conditions. Prior to each training session, all subjects participated in a 15-minute warm-up period which included jogging (10 min.) at a self-selected comfortable pace followed by joint mobility exercises (5 min.). Each training session ended with ~5 min. of cool-down activities. The daily training duration for both study groups was purposely designed to be 90 minutes.

Testing procedures

20-m sprint test. After a self-paced 3 min warm-up run, participants performed two submaximal 20-m sprints from a starting line, followed by three maximal timed sprints on outdoor athletics track with a tartan surface. Each sprint was interspersed by a 2-min walk recovery. Upon completion, each participant's time was recorded to the nearest 0.01 s on a hand-held stopwatch (Reiman & Manske, 2009). The minimum time (s) recorded in the trials was taken as a dependent variable. The test-retest reliability reported a good reliability for the 20-m sprint test (ICC = 0.83).

Squat Jump test. The SJ test is a reliable and valid test for the estimation of the explosive power of the lower limbs (Markovic, Dizdar, Jukic, & Cardinale, 2004). The SJ was performed from a starting position in which the participants' knees were at a 90-degree knee angle, without allowing any counter movement. The participants' hands were kept on their hips, thus avoiding any arm swing. The subjects were required to jump as high as possible, without performing a countermovement (pre-stretch), and to land at the same point of take-off. They were also required to rebound with straight legs when landing to avoid knee bending and alteration of measurements. The SJ test was conducted with the Beast sensor (Beast Technologies s.r.l., Brescia, Italy) that is a small wearable device designed to be fixed to a wristband that the athlete wore during tests (Balsalobre-Fernández et al., 2017). Mean velocity ($m \cdot s^{-1}$) of each trial was transferred in real time via Bluetooth 4.0 LE to the Beast app for iOS v.2.2.3, which was installed on an iPhone 6 with iOS 10.2.1 operative system. Data of each individual jump were recorded, and mean power (W), force (N) and height (cm) were calculated by applying physics laws. Each participant was given three trials, which were separated by 1-minute intervals, to complete their highest jump. The highest jump in the trials was taken as the dependent variable and used in subsequent analyses. The test-retest reliability reported a high reliability for SJ (ICC = 0.94).

Plyometric training programs

Every Tuesday and Thursday for 8 weeks, the experimental subjects replaced a part of their standard regimen with plyometric training without increasing the total training time under carefully monitored and controlled conditions. Plyometric sessions were performed after the end of the warm-up and before the traditional training of athletics and lasted for some 15 minutes. Subjects were instructed to perform all exercises with maximal effort. Experienced instructors graduate in physical education discussed and demonstrated proper exercise technique throughout the study period. The instructors consistently encouraged the subjects to maintain proper technique performance. If a subject fatigued and could not perform an exercise correctly, the exercise was stopped. The progressive plyometric training program used in this study was based on findings from previous investigations (Chu, Faigenbaum, & Falkel, 2006). The plyometric program should use the principles of progression and overload. This can be accomplished by manipulating the volume dosage (reps, sets, weight, etc.) of many different variables. The quality of the work is more important with plyometrics than the quantity of the work. In fact, the exercises were periodized to allow a progressive adaptation of ligaments, tendons and bones for a volume of work that did not initially exceed 50/60 cumulative foot touches (Bompa & Buzzichelli, 2018). From weeks 1 to 4 the 5/4 level exercises were performed, that is, with a low physical impact for the bony and muscular structures (i.e., jumping rope, A-skip, medicine ball tosses, 20 - 40 cm double leg hurdle jumping), whereas from weeks 5 to 8 those of level 3/2, that is, to high physical impact (i.e., single leg hurdle hops, successive and alternated on short distances of 5-30 m, and 30-76 cm double leg hurdle jumping). Table 2 shows the eight-week program followed by the plyometric training group.

Table 2. Eight-week program followed by the Plyometric training group (2 d·wk⁻¹).

Mesocycle	Weeks 1-4	Weeks 5-8
Plyometrics (15 minutes)	Jumping rope 1-3 x 30 seconds (basic bounce step, double basic bounce step, alternate foot step, scissor step, and double under)	Single leg hurdle hops 1-2 x 5-30 m
	A-skip 1-2 x 10 m	Alternate single leg hurdle hops 1-2 x 5-30 m
	Medicine ball tosses 1-2 x 10	Double leg hurdle jumps (30-76 cm) 1-2 x 6
	Double leg hurdle jumps (20 - 40 cm) 1-2 x 10	

All exercises were prescribed as sets x repetitions/distance/time. Inter-set rest duration was 60 sec. for weeks 1-4 and 90 sec. for weeks 5-8.

Statistical analyses

Descriptive data were calculated for all variables and presented as group mean values and standard deviations. Normality of all variables was tested using Shapiro-Wilk test procedure. Levene's test was used to determine homogeneity of variance. A multivariate analysis of variance (MANOVA) was used to detect differences between the study groups in all baseline variables. Training-related effects were assessed by 2-way analyses of variance with repeated measures (group x time). When 'Time x Group' interactions reached the level of significance, group-specific post hoc tests (i.e., paired t-tests) were conducted to identify the significant comparisons. Percentage changes were calculated as [(posttraining value – pretraining value)/pretraining value] x 100. The reliabilities of 20-m sprint time, vertical jump (Squat Jump) power, velocity, force and height average measurements were assessed using intraclass correlation coefficients; scores from 0.8 to 0.9 were considered as good, while values above > 0.9 were considered as high (Vincent & Weir, 2012). All analyses were performed using SAS Jmp Statistics (v. 14.1, Cary, NC, USA) and statistical significance was set at $p < 0.05$.

Results

All participants received the treatment conditions as allocated. Twenty-two subjects completed the training program, and none reported any training-related injury. The control and experimental groups did not differ significantly at baseline in any physical characteristics ($p > 0.05$).

Significant main effects of 'Time' were observed on the squat jump for power and height, $F_{1,20} = 11.8$ and 12.2, respectively, $p < 0.05$. Post-hoc analysis revealed that the experimental group made significant improvements both in the power and in height of the vertical jump whereas the control group showed no significant differences after 8 weeks.

Significant 'Group x Time' interactions were found for the 20-m sprint and the vertical jump power, velocity, force and height, $F_{1,20} = 6.3, 26.5, 84.6, 14.7,$ and 27.5, respectively, $p < 0.05$, with the experimental group that showed significantly greater improvements in performance compared to the control group. Pre- and post-intervention results for all outcome variables are presented in Table 3.

Table 3. Comparison of sprint running and vertical jump test performance between plyometric training group (experimental) and control group before and after 8-week trial. Data are presented as the mean (\pm SD).

Variables	Control group (n = 12)			Experimental group (n = 10)		
	Baseline	Post	Δ %	Baseline	Post	Δ %
20-m sprint (s)	3.2 (0.25)	3.3 (0.21)	1.1 (3.4)	3.2 (0.21)	3.1 (0.24) *†	-2.2 (2.1)
Squat jump Power (W)	980.1 (228.2)	948.2 (202.2)	-2.5 (10.8)	904.1 (198.5)	1064.9 (213.9) *†	18.7 (11.4)
Velocity ($m \cdot s^{-1}$)	1.7 (0.20)	1.5 (0.25)	-11.3 (6.8)	1.5 (0.13)	1.8 (0.14) *†	18.9 (10.2)
Force (N)	607.8 (89.5)	601.5 (66.2)	-8.4 (10.2)	594.2 (99.0)	639.5 (99.8) *†	7.9 (7.1)
Height (cm)	36.1 (8.6)	33.9 (6.4)	-3.7 (17.8)	28.8 (5.8)	39.7 (5.7) *†	41.0 (26.2)

A 2-way analysis of variance (group x time) assessed the statistical significance of training-related effects. M = mean; SD = standard deviation; Δ % = individual percent change. *Significantly greater improvement from baseline ($p < 0.05$). †Significantly greater improvement than in control group ($p < 0.05$).

Discussion & Conclusions

This research, through a randomized controlled trial study design with experimenter blinding, tested the hypothesis that two sessions per week of plyometric training, performed for eight weeks at the end of the warm-up and before the traditional training of athletics, can cause a greater increase in the speed and explosive strength of the lower limbs in the experimental group compared to the control group athletes who maintained their standard regimen. It was observed that subjects who added plyometric training to their standard conditioning program, without increasing the total training time, were able to achieve greater improvements in lower body speed and power as compared with subjects who participated in a conditioning program without plyometric training. The main finding was that plyometric training is, likely, to provide greater benefits to vertical jump than sprint speed.

The findings of this study agree with those showed the performance improvement in the sprint speed and vertical jump through periodized plyometric training (Chelly et al., 2014; Christou et al., 2006; Cimenli, Koc, Cimenli, & Kacoglu, 2016; Faigenbaum et al., 2007; Kadono & Enomoto, 2007; Lillegard et al., 1997). Our results are also supported by another study that has investigated the theoretical influence of force-velocity mechanical profile on jumping performance, confirming that plyometric training improves the parameters extrapolated from the squat jump test as power, strength and speed (Samozino et al., 2014). Moreover, the results agree with theories demonstrated by Fleck and Kraemer (2004), i.e., high-speed plyometrics, which consists of rapid eccentric muscle action followed by powerful concentric muscle action, is important for increasing the rate of force development during jumping and sprinting, whereas heavy training is needed to increase strength and muscle acceleration. Therefore, the effects of plyometric training and traditional athletics training, could in fact be synergistic, with their combined effects being greater than each program performed alone.

However, our experiment caused a greater increase in the jump height ($\Delta 41.0 \pm 26.2\%$, $p < 0.05$) compared to the sprint time ($\Delta -2.2 \pm 2.1\%$, $p < 0.05$) in young athletes, confirming the study results of Christou

et al. (2006) made on soccer players. This difference in the performance increase in the vertical jump compared to the sprint speed, may be due to a specificity of the plyometric exercises which mainly involved a development in projection of the vertical component (elevation) rather than horizontal (advancement). However, plyometric training seems an appropriate component of overall preparation in this context. Mero et al. (1981) found a close relationship ($p < 0.001$) between the rate of rise of the center of gravity and maximal running velocity. Perhaps because of increases in muscle power, our experimental group showed increases rather than decreases in track velocity after plyometric training program, in agreement with findings in a recent study of junior soccer players (Chelly et al., 2010).

Most previous investigations of plyometric training have also observed increased velocities; 10 weeks of such training improved speeds over distances of 0–30, 10–20, and 20–30 m ($p < 0.05$), 6 weeks of plyometric training decreased 50-m sprint times in 9 adult male athletes and a group of basketball players (Wagner & Kocak, 1997), and 7 weeks of once-weekly plyometrics decreased 20-m sprint times (de Villarreal, González-Badillo, & Izquierdo, 2008). However, Herrero et al. (2006) found no significant gains of squat jump height, or 20-m sprint time with their plyometric program, and Markovic et al. (2007) found no improvements in 20-m sprint times, even though they used a similar training program to us. These discrepancies may reflect differences in the fitness level of the study participants (physical education students vs. young athletes). So, our findings extend the existing results that state that the minimum duration of a plyometric training must be at least 6 weeks to bring significant benefits and increased jump and speed performance in young athletes (Faigenbaum et al., 2007; Hammett & Hey, 2003; Lloyd et al., 2012; Martel et al., 2005; Myer et al., 2005).

A limitation of this eight-weeks study is that a plyometric training only group was not included. However, the focus of the present study was on comparing the effects of eight weeks of a combined standard and plyometric training with a standard training in young athletes. Also, we did not assess biological maturation before the start of the study. Although there were no baseline differences in physical or performance measures between groups, it is possible that participants in each group differed in biological maturation. Lastly, our findings were limited to one category of male adolescent athletes. Future studies should extend these observations to women, to other age groups, and to other levels of competition. Furthermore, observations are also needed with differing intensities and volumes of plyometric training to determine their optimum dosage for this form of preparation.

In conclusion, we have demonstrated that the addition of plyometric training to a traditional training program was more effective than traditional training alone in improving lower limbs power performance in young athletes. Our findings highlight the potential value of combined training methods in a conditioning program aimed at maximizing power performance in youth. So, replacing a part of the standard regimen with an 8-week biweekly program of plyometric training for the lower limbs could improve sprint speed and vertical jump performance. The gains that we have observed should be of great interest for athletics coaches because performance of this sport relies greatly on specific power, jump, sprint, and throwing abilities, all of which were enhanced by the plyometric training regimen. We strongly recommend that athletics coaches implement in-season plyometric training to enhance the performance of their athletes. We would also encourage further investigation of the neuromuscular mechanisms contributing to the observed gains in performance.

Conflicts of interest - The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' contribution

Francesco Fischetti contributed to the research design, critical review of draft manuscripts, and written the manuscript. Alessio Vilardi contributed to the research design and conception, data collection and interpretation. Stefania Cataldi contributed to the writing of the manuscript and data interpretation. Gianpiero Greco contributed to the research design and conception, statistical analysis, data interpretation, critical review of draft manuscripts, and written the manuscript. Authors read and approved the final manuscript.

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