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Original article

The effect of plyometric training on the power-related factors of children aged 16 years-old

Agron Thaqi[1], *Milaim Berisha*[2], *Shkumbin Hoxha*[3]

[1] Tetovo State University, Department of kinesiology North Macedonia
[2] Istanbul Gelisim University, School of Physical Education and Sport, Coaching department, Turkey
[3] AAB College, Physical Education and Sport Department, Kosovo

Abstract. *Study Objectives:* The purpose of this study is to determine the effects of a 12-week plyometric training program on the power (explosive force), acceleration, strength endurance and body extremities speed performance of children aged 16 years-old. *Methods:* The research was conducted on a sample of 220 male volunteer students (the sample divided in to the experimental and control group) aged 16 years ± 6 months, who are students of "Fehmi Lladroci" high school from Glogoc, Republic of Kosovo. The tested plyometric training program was prepared according to the National Strength and Conditioning Association (NSCA) guides and applied 3-4 times per week (except for in the beginning and also in the last week of the program, where the program was applied twice a week). The details of the program are given in the methodology section of this paper. To process the results of the study, analysis of the data was done with the IBM SPSS Statistics 22 software. The statistics obtained were provided by two-way repeated analysis of variance (a repeated measure ANOVA). The development percentage in time were calculated by using the formula "%Δ = (x post-test − x pre-test) / pre-test *100" and values below p <0.05 were considered statistically significant. *Results:* According to the results of the study we observed that the plyometric training applied in the 12 week increased power performance (countermovement jump, standing broad jump, standing triple jump and standing medicine ball throw) by approximately 15-30%, acceleration performance (10 and 20 meter runs) by approximately 10-12%, lower and upper body extremities speed performance (plate tapping, and foot-tapping against the wall) by approximately 9-12% and strength endurance performance (sit-ups and push-ups in 30 secs) by approximately 40-45%. *Conclusion:* It was showed that the plyometric exercises applied to children aged 16 years-old increase the strength, acceleration and speed performance as well as the explosive force.

Keywords: Plyometric training, power (explosive force), acceleration speed, strength endurance

Introduction

Plyometric exercise refers to activities that enable a muscle to reach maximal force in the shortest possible time. Besides this, plyometric exercise is a quick, powerful movement using a pre-stretch, or countermovement, that involves the stretch-shortening cycle (1). In plyometric training, athletes perform a variety of explosive actions, which helps to improve their skills. Studies have shown that plyometric exercise can be beneficial to a teenagers' overall health while promoting a positive body image.

Plyometric training exercises involves jumping, hopping, and skipping that are characterized by eccentric contractions of the muscle-tendon unit immediately followed by concentric contractions which is also referred to as the stretch-shortening-cycle (SSC) (2). The beneficial effects of plyometric training on components of physical fitness (power, strength, and agility) have been well documented in the literature in the form of original work (3).

Plyometric exercises are mainly used to increase maximum power (explosive force) and acceleration. There are various physical benefits associated with being physically active at young age.

Physical activity has important implications on sports where players perform numerous explosive movements such as kicking, jumping, turning, sprinting, and changing pace and directions during the sports activity (4-8). Thus, plyometric drills usually involve stopping, starting and changing directions in an explosive manner (6).

Several research studies have confirmed that plyometric training can enhance muscle strength, power (9) and agility (10,11). We believe that the plyometric training, besides increasing power (explosive force) performance, it can also increase the acceleration, strength endurance, and body extremities of speed performance. Plyometric training cannot be applied in the same way in all age groups. Plyometrics has commonly been viewed as appropriate only for conditioning elite adult athletes. However, prepubescent and adolescent children may also benefit from plyometric and plyometric-like exercises under some conditions (for instance this age group should not apply depth jumps) (1). Age 16 is the transition phase from the restricted plyometric training to all ways of plyometric exercises. In this context, the purpose of this study is to determine the effects of a 12-week plyometric training program on the power (explosive force), acceleration, strength endurance and body extremities speed performance of children aged 16 living in Kosovo.

Material and Method

Determining the effect of plyometric training on motor abilities was used as an experimental approach to the research.

The research was conducted on a sample of 220 male students aged 16 years ± 6 months, who are students of "FEHMI LLADROVCI" high school from Glogoc, Republic of Kosovo. The sample of 220 entities was divided into the Experimental Group and Control Group. The Experimental Group included 110 volunteers (who underwent a 12-week plyometric training program). The Control Group was divided into two as those who were applied pre- and post-tests to measure the initial and final performance, and those who were not applied any special training program.

Subjects were assessed before and after the twelve weeks of the plyometric ecercise program. All measurements were taken one week before and after training at the same time of day. Tests followed a general warm-up that consisted of running, minimize drills and stretching (see the plyometric training program).

Table 1. The sample group's anthropometric descriptive information

	Groups	N	Pre-test	Post-test
			$\bar{X}$±SD	$\bar{X}$±SD
H	Plio-training	110	174.0±6.23	175.1±6.24
	Control Group	110	173.9±7.56	174.8±7.51
	Total	220	173.9±6.91	174.9±6.89
W	Plio-training	110	62.9±11.67	64.0±10.91
	Control Group	110	63.1±12.07	64.4±11.95
	Total	220	63.0±11.84	64.2±11.42
BMI	Plio-training	110	20.63±3.60	20.97±3.20
	Control Group	110	20.95±3.79	21.21±3.64
	Total	220	20.79±3.69	21.09±3.42

H: Height, W: Weight, BMI: Body mass index. $\bar{X}$±SD: Mean and standard deviation.

Motor abilities included in the research and measurement protocols

Countermovement jump (CMJ) was performed on a contact mat platform (4). Standing Broad Jump (SBJ) and Standing Triple Jump (STJ) measurements were conducted according to the Nešić' protocol (12). Standing medicine ball throw (SMBTH) is a test for assessment of explosiveness of shoulder area (the results were obtained with an accuracy of 1 cm) (12). 10-meter and 20-meter sprint tests measurements were performed according to the Bjelica and Fratrić's protocol (the result is given with an accuracy of 0.1 sec) (13). Plate tapping (PLT) and foot-tapping against the wall was used to measure movement speed individually and measured according to the standard procedure used in eurofit test battery (14). The sit-ups in 30 sec (SUP30s) test measured by bending the elbows from the straight position, then approaching the ground and straightening the elbows again. Correctly done and completed sit ups were counted and recorded as a result (15). Push-ups in 30 sec (PU30s) has validity and reliability (16) to measure the muscular strength endurance of the chest and back arm muscles (16,17). Beside motor abilities, the sample body height (H), body weight (W) and body mass index (BMI) were determined however, these variables were not included in the analysis of the study but were given to explain the study sample. Body height was measured by the martin anthropometry and the data was read with an accuracy of 0.1 cm. The body weight and body mass index ((kg) / [Height (m)]^2) were measured with medical scales (Tanita BC 545 N Innerscan Segmental Personal Body Analysis) and the data was read with an accuracy of 0.1 kg.

Applied plyometric training program

The plyometric training program was prepared according to the National Strength and Conditioning Association (NSCA) and applied 3-4 time per week (see figure 2). The volume of the training varied between 75-135 contacts per session (see figure 2). Training intensity varied between low to high load (see figure 2). Bounding drills normally covered distances greater than 98 feet (30 m) or work time approximately 20-25 secs, box jumps repeated 10-15 times. Recovery for depth jumps consisted of 5 to 10 seconds of rest between repetitions and 2 to 3 minutes between sets. The time between sets was determined by a proper work-to-rest ratio (i.e., 1:5 to 1:10) and is specific to the volume and type of drill being performed (1).

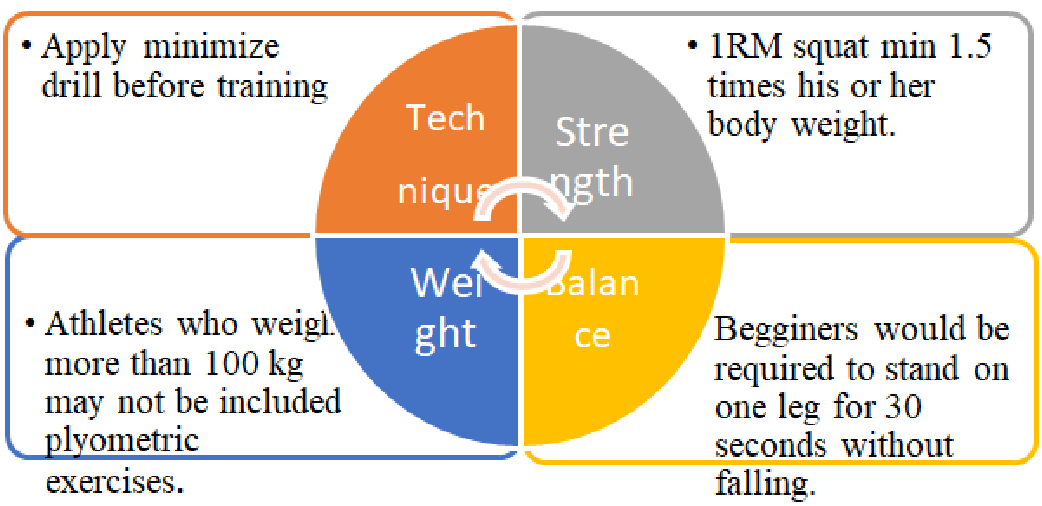

Figure 1. Safety Considerations and plyometric (Potach and Chu, 2016).

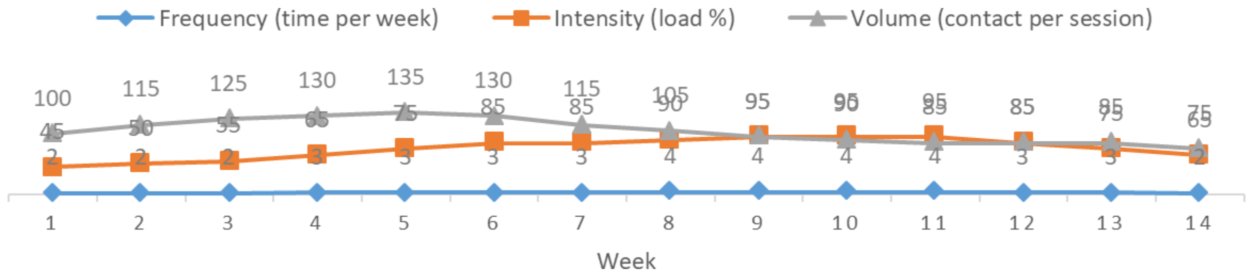

Figure 2. Plyometric training program loads

The exercise number per session is selected according to the training intensity and volume. As it can be seen in Figure 2, in the weeks when training intensity were high, training volume was low, and was selected according to the exercise volume (i.e. exercises were selected to complete the volume for the session).

Training is applied in order to provide high-intensity training for each body part (trunk, upper body, lower body) at least once a week (see Figure 3). When the training severity in the lower extremities was low, moderate and low-severity exercises were applied in trunk and upper body. The same rule applied when working with the other parts of the body. Also, plyometric training of each body part follows the intensity and volume of the past week and is connected to the next week training (see Figure 3).

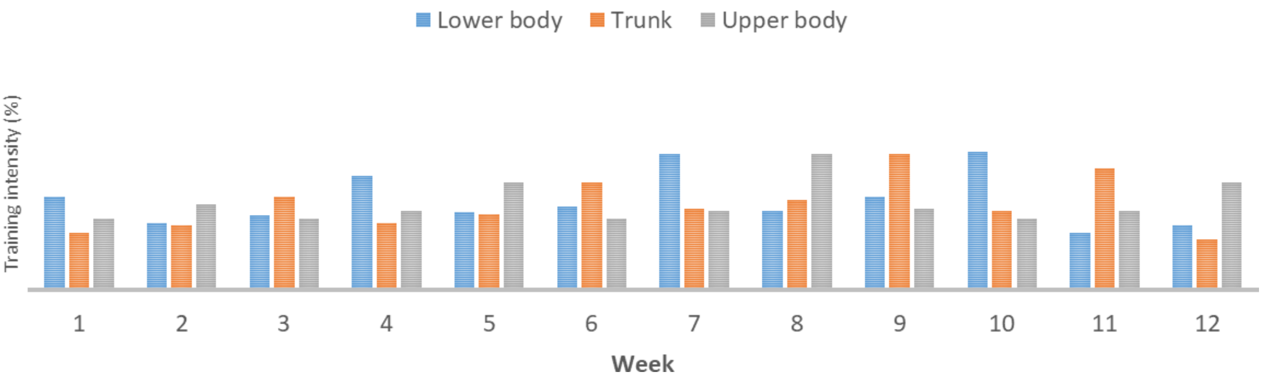

Figure 3. Training intensity and exercise selection according to body part

Table 2. Exercises included on the plyometric training program

Lower body exercises	Upper body exercises	Trunk exercises
Jump in place	Throws (power drop)	Medicine ball throw
Standing jumps	Plyometric push-ups	45^0 sit-up
Multi hops and jumps (lateral barrier hop)	Plyometric push-ups Bench Press with Medicine Ball	V – sit ups (one rapid repetition)
Bounds (leaping movement upward)	Depth Push-Ups (from Box)	Frog sit ups (one rapid repetition)
Bounds (power skip)	Alternating Med Ball Plyometric Push Up	Sit-up with medicine ball
Box drills	Push-ups (gymnasti parallels)	Med ball thow (sitt position)
Depth jumps	*Note: Depth jumps exercises were not applied between first to sixth week and in the last week.*	
Single-leg vertical jump		

Data Analysis

To process the results of the study, analysis of the data was done with the IBM SPSS Statistics 22 software. The statistics obtained were provided by two-way repeated analysis of variance (repeated measure ANOVA). The development percentage in time were calculated by using the formula "%Δ = (x post-test – x pre-test) / pre-test *100" and confidence interval was chosen as 95% and values below p <0.05 were considered statistically significant.

Results

According to the results of Table 3, it was observed that pre- and post-test averages of the countermovement jump (F= 966.720; p=.00), standing broad jump (F= 1343.167; p=.00), standing triple jump (F= 650.362; p=.00) and standing medicine ball throw (F= 556.802; p=.00) test values were statistically different according to measurement over time (CMJ: F =1771.218; p=.00, SBJ: F =833.813; p=.00, TSJ: F =422.013; p=.00, SMBTH: F =400.012; p=.00).

Table 3. Effect of plyometric training exercise on power (explosive force)

	Groups	N	Pre-test	Post-test	Total	»		%Δ	η2
			$\bar{X}$±SD	$\bar{X}$±SD	$\bar{X}$±SD	F	p		
CMJ	Plio-training	110	27.79±4.82	35.82±4.28	31.80±4.02	27.770	.00*	28.90	.11
	Control Group	110	28.44±5.27	28.44±4.90	28.44±0.00			0.00	
	Total	220	28.12±5.05	32.13±5.89	30.12±2.01				
			› F= 966.720; p=.00*			‹ F =1771.218; p=.000			
SBJ	Plio-training	110	157.7±22.16	199.0±20.21	178.3±20.65	21.510	.00*	26.19	.09
	Control Group	110	162.0±23.43	166.9±24.65	164.4±02.45			3.02	
	Total	220	159.9±22.85	182.9±27.63	171.4±11.50				
			› F= 1343.167; p=.00*			‹ F =833.813; p=.00*			
STJ	Plio-training	110	530.6±55.45	591.4±57.47	561.0±30.40	3.384	.06	11.46	.01
	Control Group	110	543.1±61.22	549.7±63.68	546.4±03.30			1.22	
	Total	220	536.9±58.61	570.5±64.02	553.7±16.80				
			› F= 650.362; p=.00*			‹ F =422.013; p=.00*			
SMBTH	Plio-training	110	453.1±61.80	525.9±61.44	489.5±36.40	11.073	.00*	16.07	.04
	Control Group	110	457.6±69.42	463.9±68.85	460.7±03.15			1.38	
	Total	220	455.3±65.61	494.8±72.20	475.1±19.75				
			› F= 556.802; p=.00*			‹ F =400.012; p=.00*			

**p<0.05. CMJ: Countermovement jump, SBJ: Standing broad jump, STJ: Standing triple jump, SMBTH: Standing medicine ball throw. $\bar{X}$±SD: Mean and standard deviation. »: Tests of between-subjects' effects. ›: Tests of Within subjects' effects (Greenhouse-Geisser). ‹: Interaction (Time*Groups). %Δ: development %. η2: partial eta squared.*

When analyzing the differences between the groups it was observed that the countermovement jump (%Δ: 28.90), standing broad jump (%Δ: 26.19), standing triple jump (%Δ: 11.46) and standing medicine ball throw (%Δ: 16.07) test of the experimental group (plio-training) had higher development percentages compared to the countermovement jump (%Δ: 0.00), standing broad jump (%Δ: 3.02), standing triple jump (%Δ: 1.22) and standing medicine ball throw (%Δ:1.38) tests of the control group (CMJ: p=.00, SBJ: p=.00, TSJ: p=.06, SMBTH: p=.00).

Table 4. Effect of plyometric exercise on acceleration ability factors

	Groups	N	Pre-test	Post-test	Total	»		%Δ	η2
			$\bar{X}$±SD	$\bar{X}$±SD	$\bar{X}$±SD	F	p		
10m RUN	Plio-training	110	2.408±.35	2.103±.23	2.256±0.15	6.481	.01*	-12.67	.02
	Control Group	110	2.390±.33	2.317±.30	2.354±0.04			-3.05	
	Total	220	2.399±.34	2.210±.29	2.305±0.09				
	› F= 140.031; p=.00*					‹ F =52.581; p=.00*			
20m RUN	Plio-training	110	3.974±.53	3.541±.35	3.758±0.22	2.136	.14	-10.90	.01
	Control Group	110	3.888±.48	3.798±.45	3.843±0.04			-2.31	
	Total	220	3.931±.50	3.670±.42	3.800±0.13				
	› F= 161.382; p=.00*					‹ F =69.509; p=.00*			

**p<0.05. 10mRUN: 10 Meters run, 20mRUN: 20 Meters run. $\bar{X}$±SD: Mean and standard deviation. »: Tests of between-subjects' effects. ›: Tests of Within subjects' effects (Greenhouse-Geisser). ‹: Interaction (Time*Groups). %Δ: development %. η2: partial eta squared*

According to the results of Table 4, it was observed that pre- and post-test averages of the 10 meters run (F= 140.031; p=.00) and 20 meters run (F= 161.382; p=.000) tests values were statistically different according to measurement in time (10mRUN: F =52.581; p=.000, 20mRUN: F =69.509; p=.000*).

When analyzing the differences between the groups, it was observed that the 10 meters run test (%Δ: -12.67) and 20 meters run (%Δ: -10.90) test of the experimental group (plio-training) had higher development percentages compared to the 10 meters run (%Δ: -3.05) and 20 meters run (%Δ: -2.31) tests of the control group (10mRUN: p=.01, 20mRUN: p=.14).

According to the results of the Table 5 it was observed that pre- and post-test averages of the plate tapping (F= 252.953; p=.00), foot-tapping against the wall (F= 110.088; p=.00), sit ups in 30 secs (F= 744.410; p=.00) and push-ups in 30 secs (F= 510.631; p=.00) tests, values were statistically different according to measurement over time (PLT: F =126.764; p=.00, FTAW: F =41.907; p=.00, SUP30s: F =619.485; p=.00, SMBTH: F =387.229; p=.00).

When analyzing the differences between the groups, it was observed that the plate tapping (%Δ: -12.43), foot-tapping against the wall (%Δ: -9.32), sit ups in 30 secs (%Δ: 40.00) and push-ups in 30 secs (%Δ: 45.83) test of the experimental group (plio-training) had higher development percentages compared to the plate tapping (%Δ: -2.18), foot-tapping against the wall (%Δ: -2.25), sit ups in 30 secs (%Δ: 2.01) and push-ups in 30 secs (%Δ:2.87) tests of the control group (PLT: p=.23, FTAW: p=.45, SUP30s: p=.00, PU30s: p=.00).

Discussion

According to the results of Table 3 it was observed that pre- and post-test averages of the countermovement jump, standing broad jump, standing triple jump and standing medicine ball throw tests values were statistically different according to measurement over time. In the study showed that two weeks of plyometric training, including various types of jumping, significantly increased vertical and horizontal jumping ability. Furthermore, the increase in vertical jumps was greater than in horizontal jumps in male sprinters (18). The literature has shown that vertical jump height improves as quickly as four weeks after the start of a plyometric training program (1). According to the literature the, data indicates that power training might provide some advantage for increasing jump performance (19). According to the literature, strength performance of the athletes under 17 years old was improved by plyometric exercises (upper body, trunk and lower body) (20). A period of 10 weeks or more (more than 20 sessions of plyometric training in total) has been suggested to maximize the probability

Table 5. Effects of plyometric exercise on upper body speed and strength endurance

	Groups	N	Pre-test	Post-test	Total	»		%Δ	η2
			$\bar{X}$±SD	$\bar{X}$±SD	$\bar{X}$±SD	F	p		
PLT	Plio-training	110	10.86±1.66	09.51±1.32	10.18±0.68	1.404	.23	-12.43	.00
	Control Group	110	10.55±1.65	10.32±1.63	10.43±0.12			-2.18	
	Total	220	10.71±.166	09.82±1.53	10.31±0.45				
			› F= 252.953; p=.00*			‹ F =126.764; p=.00*			
FTAW	Plio-training	110	14.05±2.18	12.74±2.11	13.39±0.66	.572	.45	-9.32	.00
	Control Group	110	13.77±2.31	13.46±2.17	13.61±0.15			-2.25	
	Total	220	13.91±2.25	13.10±2.16	13.50±0.41				
			› F= 110.088; p=.00*			‹ F =41.907; p=.00*			
SUP30s	Plio-training	110	19.0±3.78	26.6±3.85	22.8±3.80	26.932	.00*	40.00	.11
	Control Group	110	19.9±4.24	20.3±4.17	20.1±0.20			2.01	
	Total	220	19.5±4.03	23.4±5.09	21.4±1.95				
			› F= 744.410; p=.00*			‹ F =619.485; p=.00*			
PU30s	Plio-training	110	16.8±7.38	24.5±7.36	20.6±3.85	8.783	.00*	45.83	.03
	Control Group	110	17.4±7.97	17.9±8.02	17.6±0.25			2.87	
	Total	220	17.1±7.67	21.3±8.36	19.1±2.10				
			› F= 510.631; p=.00*			‹ F =387.229; p=.00*			

**p<0.05. PLT: Plate tapping, (FTAW): Foot-tapping against the wall, SUP30s: Sit ups in 30 secs, PU30s: Push-ups in 30 sec. $\bar{X}$±SD: Mean and standard deviation. »: Tests of between-subjects' effects. ›: Tests of Within subjects' effects (Greenhouse-Geisser). ‹: Interaction (Time*Groups). %Δ: development %. η2: partial eta squared.*

of obtaining significant performance improvements in athletes (21). When analyzing the differences between groups, it was observed that the countermovement jump, standing broad jump, standing triple jump and standing medicine ball throw test of the experimental group (plio-training) had higher development percentage compared to the same tests of the control group. According to the literature, 10 weeks of lower limb plyometric training, added to a standard in-season regimen, increased vertical, as well as horizontal, jump ability more than standard training. With plyometric training, absolute peak power increased by an average of 9.1%, though similar gains (10%) were achieved using a standard training approach (22).

In general, when analyzing the differences between groups, it was observed that the countermovement jump (%Δ: 28.90), standing broad jump (%Δ: 26.19), standing triple jump (%Δ: 11.46) and standing medicine ball throw (%Δ: 16.07) test of the experimental group (plio-training) had higher development percentages compared to the same tests of the control group; countermovement jump (%Δ: 0.00), standing broad jump (%Δ: 3.02), standing triple jump (%Δ: 1.22) and standing medicine ball throw (%Δ:1.38). Plyometric training, either alone or in combination with other training modalities, has the potential to enhance a wide range of performance aspects, including jumping, sprinting, agility and endurance performance, in children and young adults (23).

According to the results of Table 4, it was observed that pre- and post-test averages values of the 10 and 20 meters run tests were statistically different according to measurement over time. When analyzing the differences between groups, it was also observed that the 10 meters run test (%Δ: -12.67) and 20 meters run (%Δ: -10.90) test of the experimental group (plio-training) had higher development percentages compared to the same tests of the control group; 10 meters run (%Δ: -3.05) and 20 meters run (%Δ: -2.31). Regarding training volume within a single session, the literature reported similar improvements on sprint time and jump performance compared to high volume training in pre-adolescent children (24).

According to the results of the study, it was observed that an applied plyometric training program increased the practitioners' acceleration performance (10 meters run experimental group %Δ -12.67 and control group %Δ -3.05, and 20 meters run experimental group %Δ -10.90 and control group %Δ -2.31) by approximately 10-12% when the development of the same abilities in the control group were approximately 2-3%. Many studies have reported statistically significant and positive effects of a plyometric program on sprint performance (25,21, 26).

According to the results of Table 5, it was observed that pre-test and post-test averages of the plate tapping, foot-tapping against the wall, sit ups in 30 secs and push-ups in 30 secs tests values statistically different according to measurement over time. The plyometric training program increased the practitioners' reaction time performance of the upper extremities (plate tapping; experimental group %Δ -12.43 and control group %Δ -2.18), lower extremities (foot-tapping against the wall; experimental group %Δ -9.32 and control group %Δ -2.25), strength endurance of the abdomen (sit ups in 30 secs; experimental group %Δ 40.00and control group %Δ 2.01) and strength endurance of the upper extremities (push-ups in 30 secs; experimental group %Δ -45.83 and control group %Δ -2.87) approximately 9-45% when the development of the same abilities in the control group only showed an improvement of approximately 2%. According to the literature, tapping tests such as foot-tapping and plate tapping, are related to the velocity-dependent increase in tonic stretch reflex ("muscle tone") that characterizes limb spasticity as one component of upper motor neuron syndrome, which functionally impairs fast movements and rapid repetitive limb movements (27-29). The literature showed the correlations between plyometric movements and stretch reflex (1), showing that plyometric training increases the performance of foot-tapping and plate tapping tests.

As it can be seen in the result of the study, all plyometric exercise variations can be applied at the age of 16 by considering the conditions to participate in the plyometric exercises that are valid for all age groups (see Figure 1). The results of Parnow's study showed that the plyometric exercise affected power, speed, acceleration and strength endurance significantly after 4-week training in 16 years old athletes (35). Also, it has been demonstrated that in-season lower-body plyometric training conducted in 16 years old soccer players resulted in significant improvements in various competencies of physical fitness such as power, speed, agility etc. (36).

Conclusion

As a result of the study, we observed that plyometric training affected the strength performance of the lower body and upper body trunk, and improved the results by approximately 15-30%.

The highest effect of the plyometric training recorded in the countermovement jump performance was 28.90%. A similar impact was detected on the acceleration ability, where the 10 meters run performance impacted by the plyometric training was 12.67% and 20 meters run performance improved by 10.90%. The performance of the upper (12.43%) and lower (9.32%) extremities also were impacted by plyometric training. All these results are consistent with the literature. The performance of the strength endurance (sit ups in 30 secs developed by 40.00% and push-ups in 30 secs by 45.83%) impacted by the plyometric training more than the literature indicated (see the results section). As we can see, the highest impact of plyometric training was shown on the push-up performance. This can verify that plyometric training is more important on motor abilities such strength endurance performance than what the literature indicates.

However, it has been repeatedly shown that plyometric exercise increases muscular power for participants in a formal training program (29,30,31,32,33) and research has yet to determine whether mechanical or neurophysiological adaptations account for the improvement.

Based on that information we suggest the following:

- Research on the determination of the type of adaptations that plyometric training makers can handle.
- Using plyometric training not just to improve jumping performance, but to increase other abilities such as acceleration, rapid movement (reaction time), speed of the upper and lower extremities and strength endurance.

Conflicts of Interest

The authors declare that there is no conflict of interest in this manuscript.

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Correspondence:
Milaim Berisha
School of Physical Education and Sport, Istanbul Gelisim University, Istanbul, Turkey
E-mail: mberisha@gmail.com