

The Effect of Plyometric Training on Lower Body Strength in Preadolescent Athletes

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Abstract: *In athletics, strength plays a special role, given that its development is focused on improving the speed of movement. The main form of expressing strength in athletics is speed-strength (explosive strength, take-off), which is representative for sprinting, jumping and throwing. Specialised studies have revealed that one of the most effective training methods used to develop explosive strength, also called explosive power, is the training based on plyometric exercises, but studies regarding the use of this method for the prepubertal age segment in athletic training are scarce. The purpose of this research is to investigate the degree of improvement in explosive strength in preadolescent athletes with the help of weekly plyometric training as compared to the control group. The research was carried out at the School no. 190 between 20 February and 17 June 2017. In order to conduct the experimental research, 42 athlete subjects of both genders, aged 11 to 13 years, were investigated. The experimental group was made up of 20 athletes, members of the Municipal Sports Club in Bucharest. The control group included 22 athlete subjects of both genders, who were trained by other coaches. Both groups performed four training sessions per week for 17 weeks. Analysing the results of the experiment, we can conclude that plyometric workouts contribute to the development of lower body strength in preadolescent athletes.*

Keywords: *plyometric training; strength; preadolescent athletes; vertical jump; standing triple jump; penta-jump.*

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Introduction

It is known that lifestyle and healthy/unhealthy behaviours established during childhood and adolescence can become lifelong habits since dramatic physiological and psychological adaptations take place at these ages. It is argued that children not practicing physical exercise will never fully develop their genetic potential in terms of motor skills. (Tabacchi et al., 2019)

By growth, maturation and development, we understand the biological mechanisms that act in the human body until reaching adulthood. If the growth process involves quantitative aspects related to weight gain, volume and body size, „development is related to a biological and behavioural context involving both processes mentioned above, added to by environmental stimuli (learning and experience). Puberty is the phase that comprises these three aspects and usually occurs around 10 to 12 years of age in girls and between 12 and 14 years in boys. This phase is associated with morphological and hormonal changes, higher neuromuscular organization, and refinement of more complex motor activities such as locomotion” (Alvares et al., 2020).

Multiple studies point out that physical activity is a mechanism for beneficial structural and functional alterations to the brain (e.g., increased neurotrophins, cerebral blood flow, or grey matter volume), which, in turn, enhances cognitive outcomes. In addition, regular physical activity leads to better circulation and oxygen supply to the brain, an increase in bone and muscle density, and a higher tolerance of stress (Tabacchi et al., 2019).

Athletics training is a set of educational actions with psychological, social, economic, medical, ergonomic, ethical implications and not only, whose main objective is the training of children for their functional integration into social and productive life. This training must be in accordance with the age characteristics, individual characteristics (skills, interests, aspirations) and psychophysiological demands.

Hollmann and Hettinger (1980, as cited by Sabău, 2014) agree with strength training during childhood, provided that certain instructions are followed, such as:

- allow sufficient recovery time after strength training;
- gradually change the loads;
- avoid working with barbells before and during growth processes because of negative consequences on the spine;

- avoid unilateral effort, which can affect the musculoskeletal system. in morpho-functional terms;

- avoid long-term effort because it can affect blood circulation.

It is known that the richer the child's motor background, the more the child becomes inventive and able to find solutions to new situations. This justifies the relevance of teaching strategies applied to early athletic training, which involve compliance with certain educational intervention principles such as: multilateral physical development, exploiting and experiencing as many forms of fundamental motor behaviours as possible, encouraging the association of various motor behaviours and thus combining running, jumping, throwing, changes of position, etc., which are aimed to both exploit all facets of the child's motor potential and avoid the onset of specialized early gestures.

Through play activities, children increase their lower limb strength by running, jumping, cycling, skipping, jumping over obstacles, and their arm strength improves by carrying objects, climbing, throwing and handling objects.

Using the skipping rope in sports training enjoys a lot of popularity among children, especially girls, and proves to be effective in developing endurance. Thus, learning to handle the rope is not very difficult for children, and its effectiveness in improving endurance, speed, coordination, take-off and mobility is high. Regarding rope jumping, a French female athlete well known for her explosive strength said that used to play with the skipping rope and elastic during all breaks and her free moments since she was in primary school, which certainly means 500-600 jumps per day, therefore 3,500-4,000 per week and 14,000 to 16,000 per month! Rope jumping is a good exercise to improve lower limb strength, coordination and rhythm (Pauly, 2007).

One of the most effective training methods, especially at this age, is the relay race (athletic routes) designed for teaching purposes, with progressively increased complexity and difficulty, which simultaneously require the performance of various categories of skills, mainly the basic ones: running, jumping and throwing performed either separately or in combination, preferably in speed-agility conditions. The teacher has to use the playful aspect of the games and the motor transfer to reach maximum efficiency (Bălan & Shaao, 2014).

Given that strength plays a special role in athletics, its development is focused on improving the speed of movement. The main form of manifestation of strength in athletics is speed-strength (explosive strength, take-off), which is representative for sprinting, jumping and throwing, being

also a basic parameter that emphasizes the physical fitness level (Pricop, Leonte, & Popescu, 2016).

Explosive strength is the property of producing powerful momentum in the shortest time possible. It defines the speed of producing power from the beginning of the movement up to reaching the maximum level of expression (Pelin, Netolitzchi, & Răchită, 2014).

In athletics, power is essential in most events; in sprinting events, a start as fast and explosive possible depends on how high the starting power is, on the athlete's ability to recruit as many fast fibres as possible at the beginning of the movement; in the pre-stretching position of the muscles (flexed knees), which is characteristic of the starting position, elastic elements in the muscles store kinetic energy that acts as a spring when the firing of the starter's gun is heard (Bompa, 2010); the power developed by elite athletes at the start is 132 kg on the attacking leg and 102 kg on the rear leg; acceleration power is also crucial to forcefully push off the ground, which is specific to the propulsion phase that dictates the improvement of final times in sprinting events; thus, the ground force is two or three times higher than the athlete's body weight (Bompa, 2010); athletic jumping events are marked by the take-off and landing power of the athletes; thus, the take-off occurs after a speed run over the approach distance, during which muscles are pre-stretched and store kinetic energy; to increase power, plyometric training must be used, especially depth jumps that imitate the landing take-off, where the athlete must have a flexed position in order to reduce impact forces on landing. Plyometric training involves multiarticular movements that lead to engaging the elastic properties of the muscles and a better jumping ability of the athlete.

A study conducted by Diekmann and Letzelter (as cited by Weineck, 1997, p. 279) highlights that the strength-speed continuum can be improved since primary school; thus, following a 12-week training with two sessions of 30-35 minutes per week, the experiment group recorded significantly better performance compared to the control group.

The study by Polakovicova et al. (2018) shows significant gender differences in vertical jump height between elite male and female volleyball players aged 15 years. Vertical jump height constantly increases with increasing age in males. In females, the effect of age on vertical jump height is insignificant.

Most recent studies have shown that strength gain in preadolescents is achieved by improving the excitation-contraction coupling, the force transmission to bone segments rather than by increasing muscle mass, which occurs only after puberty.

Research purpose

The purpose of this research is to investigate the degree of improvement in explosive strength in preadolescent athletes with the help of weekly plyometric training as compared to the control group.

Hypothesis

Systematic plyometric training performed for 17 weeks leads to significant improvements in explosive strength assessed by indirect methods in preadolescent athletes.

Methodology

Subjects

The research was carried out at the School no. 190 between 20 February and 17 June 2017. The research experiment was conducted on 42 athlete subjects aged between 11 and 13 years, both male and female. The experimental group was made up of 20 athletes, members of the Municipal Sports Club in Bucharest. The control group included 22 athlete subjects of both genders, who were trained by other coaches. Both groups performed four training sessions per week during the 17 weeks. Plyometric workouts were administered weekly and lasted 35 to 45 minutes during the athletics lesson.

Participants were healthy people, who had no injuries that might have worsened throughout the tests and who had at least 3 years of experience in athletic training.

Before the experiment, subjects were verbally informed about the test characteristics and the types of assessment used. All subjects agreed to how the experiment would be conducted.

Research methods

The research methods used in this study were: scientific documentation (for the theoretical background of the paper), experimental method, graphical method, mathematical and statistical method, test method and measurement method.

Statistical calculations were performed using the computer product IBM SPSS - Statistical Package for the Social Sciences, t-Test.

The motor tests are:

- Vertical jump: the test consists in performing a maximal vertical jump starting from a position with knees bent at 90⁰; the jump is performed

with the arm up, and the jump height is measured between the spot marked by the raised arm before the jump and the highest point marked during the test (jump); the landing spot will be identical with the initial starting position, otherwise the test is not considered correct.

- Standing long jump: from standing with legs apart and soles at shoulder width, arms up, running start by bending and stretching the legs simultaneously with the arm swing in the sagittal plane, energetical impulsion, long jump and landing on both feet with bent knees. The distance from the starting line to the last mark left by the athlete in the sand pit is measured. The best result of the two attempts will count.

- Standing triple jump: from standing with legs apart and soles at shoulder width, arms up, two skipped steps are performed, and the third consists in landing on both feet with bent knees in the sand pit. The distance from the starting line to the last mark left by the athlete in the sand pit is measured. The best result of the two attempts will count.

- Standing penta-jump: is similar to standing triple jump but involves performing four skipped steps on the track, while the fifth consists in landing on both feet with bent knees in the sand pit.

In order to assess lower body strength, four tests were selected; the subjects performed them twice, and their best performance was recorded. Standing triple jump and penta-jump are used in athletics to assess and compare the level of training of an athlete, good results in the two tests correlating with a high level of explosive power.

In fact, an experienced coach can assess quite accurately only from the ground contact during a test if the athlete is sufficiently trained for the target competitions.

Training methodology

The training programme for the experiment group was designed taking into account the age characteristics of children and aimed to prevent the risk of musculotendinous and joint injuries, which was achieved through careful toning of the entire muscle system.

It should be noted that we also sought to avoid monotony by alternating the means and conditions of execution, and each training programme ended with exercises for the strengthening of abdominal and back muscles, as well as stretching and mobility exercises.

As regards the use of this type of training, there are legitimated concerns about the high risk of injury to athletes, but recent research has shown that if the training is adapted to the characteristics of children, the incidence of injury is lower (Praagh, 2008).

The key element in addressing this method at younger ages is the patience of coaches, who must respect the principle of progression in order to prevent injury. For the same purpose, the training of children must be scheduled according to their previous sports experience.

In the case of plyometric exercises, progression involves gradually inserting the five levels of intensity of plyometric exercises, carefully selecting the height of the plinth/bench with which children work, the number of repetitions, the breaks granted, the combination of exercises used, initially proposing actions on both feet, and then on one foot, and passing from simple to complex exercises.

Knowing in detail each proposed method, technique, exercise, correctly choosing each training practice from a multitude of possibilities, but especially understanding that each person is a unique and unrepeatable experience, a living book of knowledge and discovery, a unique and infinite universe of possibilities, all of this represents the proper horizon for achieving optimal muscle development (Geambaşu, 2018, p. 10).

At the age concerned, the plyometric programme designed for athletic training also included depth jumps performed only on both feet in order to prevent possible injury, and the number of repetitions per lesson was limited. It is recommended that only low drop jump heights be included in plyometric training to limit the probability of sustaining injuries (Bassa et al., 2012), and landings should be performed only on soft surfaces. Also, the design of this training programme involved using exercises already known or partially known by the subjects so that their attention was not focused on learning new skills.

The originality of this research consists in the very fact that there are few studies regarding the impact of plyometric training on explosive strength in preadolescent athletes, given that most of them address plyometric training for other branches of sport or other age segments. Another aspect of originality in this research is the fact that it provides benchmarks for successful athletic training addressing this age sample, which was strengthened by the results of children at the National Athletics Championships. Thus, athletes belonging to the Municipal Sports Club in Bucharest won the highest number of national medals for the category Children 1, 2, 3 in that calendar year, most of these results being obtained by children from the experimental group.

We present below the range of plyometric exercises used in the 17 programmes aimed at developing explosive leg strength and performed in the second part of athletic lessons.

Table 1. The main training indicators

Training indicators	Experiment group
Number of training days	68
Number of plyometric workouts	17
1. bouncing up and down while moving forward over 10 m	15
2. knee-to-chest jump while moving forward over 10 m	15
3. tucked-to-tucked jump, with an emphasis on the height of the jump over 10 m	15
4. diagonal half-tucked jump with alternating support while moving forward over 10 m	30
5. left/right single-foot jump while moving forward over 5 m	25
6. standing long jump off the plinth (40 cm in height) and landing in the sand pit	30
7. standing long jump off the plinth (40 cm in height) and landing in the sand pit, followed by explosive high jump	30
Special Training (plyometrics) 8.in-depth jumps on both feet over 6 plinths (20 cm in height)	24
9. plinth jump (20 cm in height) on both feet with return	120
10. plinth jump (30 cm in height) with alternating support, with an emphasis on the full extension of the support leg	240
11. lunge jump and landing on the same advanced foot, with an emphasis on reaching the maximum Height	240
12. skipped steps over 10 m with standing start on both feet and landing in the sand pit	12
13. sequences of two hop steps, one skipped step over 10 m and landing in the sand pit	16
14. simple jump with double foot take-off, with knees extended and then slightly bent over 12 cones	144
15. simple jump with double foot take-off between 12 cones	144
16. one leg jump over 12 cones	288
17. jump from standing to standing straddle with half-bent knees near the 12 cones	144

18. zigzag jump on both feet near the cones	144
19. lunge jump with leg scissors and landing on the other foot, with an emphasis on reaching the maximum height	120
depth jump off the plinth (40 cm in height) and landing on both feet in the sand pit, followed by standing long jump	24
21. knee-to-chest jump over obstacles (30 cm in height)	48
22. simple jump with double foot take-off over obstacles	48
23. jumping over obstacles with the right leg	48
24. jumping over obstacles with the left leg	48
25. from running with knees up, jumping over obstacles from the lateral right side	48
26. from running with knees up, jumping over obstacles from the lateral left side	48
27. lunge jump with the rear foot lying on the slat of the fixed ladder, with an emphasis on the full extension of the front leg	72
28. standing long jump off the plinth (30 cm in height) in the sand pit, followed by three skipped steps	16

Source: original data resulting from research

Results

Table 2. Statistical indicators by group and test

Statistical indicators by group	Results by test				
	Standing long jump	Standing triple jump	Standing penta-jump	Vertical jump	
Experiment					
Mean ± st. dev. - initial	187.3 ± 11.1	523.0 ± 27.1	862.7 ± 47.8	28.0 ± 3.6	
Mean ± st. dev. – final	189.9 ± 11.8	538.6 ± 28.0	907.1 ± 48.8	31.8 ± 4.9	
Coefficient of variation	5.9% 6.2%	5.2% 5.2%	5.5% 5.4%	13.0%	15.5%
Dependent Paired t-Test	0.007 < 0.01	< 0.001	< 0.001	< 0.001	
Control					
Mean ± st. dev. - initial	185.6 ± 8.0	494.2 ± 20.0	872.8 ± 33.1	27.8 ± 2.9	

Mean ± st. dev. – final	187.5 ± 9.4	508.0 ± 21.4	877.0 ± 34.2	29.0 ± 3.2
Coefficient of variation	4.3% 5.0%	4.1% 4.2%	3.8% 3.9%	10.6% 11.1%
Dependent Paired t-Test	0.002 < 0.01	< 0.001	0.493 > 0.05	0.025 < 0.05
Experiment-Control				
Mean ± st. dev. - Exp.	189.9 ± 11.8	538.6 ± 28.0	907.1 ± 48.8	31.8 ± 4.9
Mean ± st. dev. - Ctrl.	187.5 ± 9.4	508.0 ± 21.4	877.0 ± 34.2	29.0 ± 3.2
Coefficient of variation	6.2% 5.0%	5.2% 4.2%	5.4% 3.9%	15.5% 11.1%
Dependent Paired t-Test	0.482 > 0.05	< 0.001	0.028 < 0.05	0.037 < 0.05

Source: original data resulting from research

Observations

Sig. = Significance

Statistical significance of p-value for threshold:

p < 0.001 – mean difference is highly significant (99.9% confidence)

p < 0.01 – mean difference is significant (99.9% confidence)

p < 0.05 – mean difference is significant (99.9% confidence)

p > 0.05 – mean difference is insignificant

The progress registered by the experiment group is 2.6 cm, the average increase is 1.4% and is statistically significant, $p = 0.007 < 0.01$. The control group registered a progress of 1.9 cm, the average increase of 1.0% is significant, $p = 0.002 < 0.01$.

At the final tests the mean of the experimental group is higher than that of the control group with. 2.4 cm. The percentage difference is 1.3% and is not statistically significant, $p = 0.482 > 0.05$.

In the graph in figure 1, the average values obtained by the two groups in the two tests are shown.

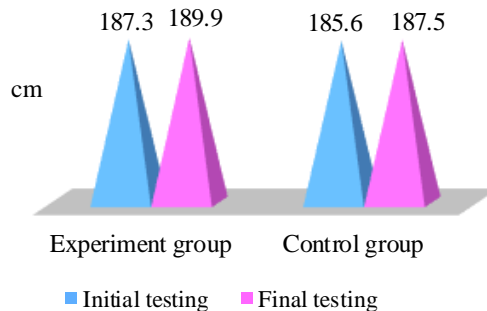


Figure 1. Mean values – Standing long jump

Source: figure arising from the original research activity

The average increase in the experiment group is 15.6 cm, 3.0% percentage and is statistically significant, $p < 0.001$. The control group registered an average progress of 13.8 cm, the increase of 2.8% is significant, $p < 0.001$.

The average of the experimental group, at the final tests, is higher than that of the control group by 30.6 cm. The percentage difference is 6.0% and is statistically significant, $p < 0.001$.

In the graph in figure 2 the average values obtained by the two groups at the initial and final tests are illustrated.

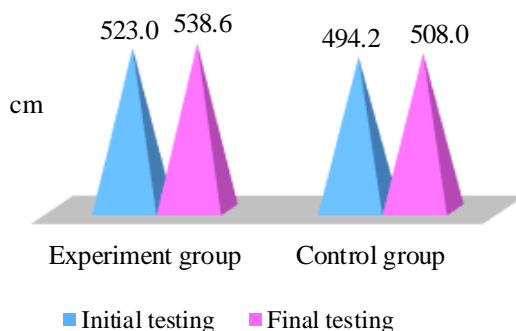


Figure 2. Mean values – Standing triple jump

Source: figure arising from the original research activity

In the experiment group, the average increase is 44.3 cm, 5.1% percentage and is statistically significant, $p < 0.001$. In the control group, the average growth is 4.2 cm, 0.5% percentage. The increase is not significant, $p = 0.493 > 0.05$.

At the final tests the average of the experiment group is higher than that of the control group by 30.1 cm. The percentage difference is 3.4% and is statistically significant, $p = 0.028 < 0.05$.

In figure 3, the average values obtained by the two groups at the initial and final tests are plotted.

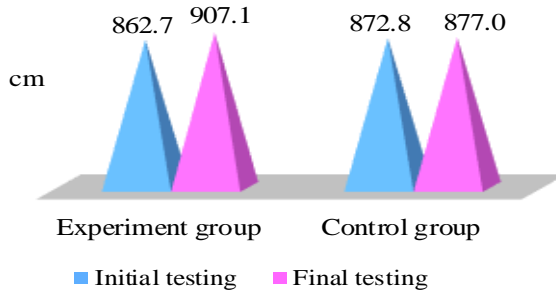


Figure 3. Mean values – Standing penta-jump

Source: figure arising from the original research activity

The average increase recorded by the experiment group is 3.8 cm, the percentage increase is 13.6% and is statistically significant, $p < 0.001$. The control group registered an average increase of 1.2 cm, the percentage increase of 4.3% is significant, $p = 0.025 < 0.05$.

At the final tests the mean of the experimental group is higher than that of the control group with 2.8 cm. The percentage difference is 9.5% and is statistically significant, $p = 0.037 < 0.05$.

In the graph in figure 4 the average values obtained by the two groups at the initial and final tests are presented.

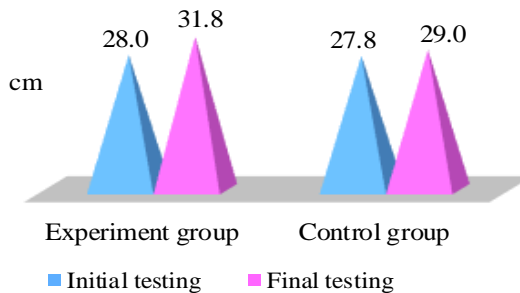


Figure 4. Mean values – Vertical jump

Source: figure arising from the original research activity

Regarding the experiment group, we notice that the averages values have increased in the final assessment for all tests. According to the determined coefficients of variation, the results obtained by athletes are homogeneously spread around the means for all tests, except vertical jump,

where the results are relatively homogeneously spread in the final test. Mean differences between final tests and initial tests are assessed, in terms of statistical significance, by the p-value of the significance threshold determined with the two-tailed dependent t-test. For standing triple jump, standing penta-jump and vertical jump, the p-values is < 0.001 . For standing long jump, the significance threshold is equal to $0.007 < 0.01$. Differences are statistically significant in all tests.

Regarding the control group, we note increased averages in the final assessment for all tests. The results obtained by athletes are homogeneously spread around the means in both assessments, for all tests. Mean differences between final tests and initial tests are statistically significant for standing long jump, where the p-value = $0.002 < 0.01$, standing triple jump, where the p-value is < 0.001 and vertical jump, where the p-value = $0.025 < 0.05$. For standing penta-jump, differences are not statistically significant since the threshold value is $p = 0.493 > 0.05$.

To compare the average values obtained by the experiment and control groups in the final assessments for each test, the two-tailed independent t-test was used. The results show that the averages of the experiment group are higher in all four tests, but they are statistically significant only for standing triple jump, standing penta-jump and vertical jump. The significance threshold is $p < 0.001$ for standing triple jump, $p = 0.028 < 0.05$ for standing penta-jump and $p = 0.037 < 0.05$ for vertical jump. For standing long jump, mean differences are not statistically significant since the threshold value is $p = 0.4482 > 0.05$.

We mention that, for standing long jump, standing triple jump and standing penta-jump, we applied the independent t-test with equal variances not assumed, according to the value Sig. > 0.05 provided by the Levene test. For vertical jump, the Levene test provides the value Sig. < 0.05 . In this case, we used the independent t-test with equal variances assumed.

Discussion

Specialty studies (and not only) have revealed that among the most effective training methods used to develop explosive strength, also called explosive power, is the training based on plyometric exercises, but studies regarding the use of this method for the preadolescent age segment in athletic training are scarce.

Recent studies have highlighted that the standing penta-jump test is a good tool to estimate anaerobic leg power and a very practical means of selection and/or orientation of young people to explosive sports (Bouhlej et

al., 2006); also, the study by Chamari et al. (2008) shows that the standing penta-jump test can be used as a diagnosis tool for explosive strength in elite football players.

Statistical processing emphasised that both groups improved their take-off, which was determined by indirect methods. However, comparing the average values obtained by both groups of athletes in the final tests, it can be seen that the averages of the experiment group are higher in all four tests, but statistically significant only for standing triple jump, standing penta-jump and vertical jump, the significance threshold being $p < 0.001$ for standing triple jump, $p = 0.028 < 0.05$ for standing penta-jump and $p = 0.037 < 0.05$ for vertical jump.

The obtained results are consistent with other studies conducted by specialists; thus, the training based on plyometric exercises proved to be more effective in developing lower-body explosive power and agility in young college football players compared to 12 sprint training sessions performed over 6 weeks (Vadivelan & Sudhakar, 2015).

According to Hammami et al. (2019), a 9-week plyometric training led to the improvement of some important components of physical performance in U14 female handball players.

The study by McKinlay et al. (2017) confirms that neuromuscular activation and rate of torque development in dynamic contractions are related to jump performance, while isometric contractions are not in young soccer players aged 11-13 years. Thus, workouts that involve dynamic muscular contractions are most indicated for improving take-off performance, muscle power, lower limb strength and overall sport-specific skills.

Another study emphasises the effect of a 10-minute jumping workout performed over 6 weeks, with a frequency of 3 times per week. It has been found that this type of training leads to an improvement in vertical jump for pre- and post-pubertal girl and boys. Thus, the recorded results were as follows: 24.9% for prepubertal girls and 31.8% for post-pubertal girls; 10.5% for prepubertal boys and 15.1% for post-pubertal boys (Praagh, 2008).

The study conducted by Michailidis et al. (2019) indicates that a short-term combined programme of plyometric training and COD exercises can improve jumping ability, acceleration and endurance parameters in young footballers after a 6-week training programme.

Conclusion

We can thus conclude that using widely selected plyometric exercises (including depth jumps) has been extremely effective for reaching the target of developing explosive strength in the experiment group athletes after 17 weeks of application of the proposed programme, without the occurrence of musculotendinous and joint injuries.

Acknowledgments

All authors have equally contributed in this study and should be considered as main authors.

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