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The effects of experimental program on the explosive strength of lower limbs in male adolescents

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Abstract

Background and Study Aim Various experimental programs for the development of motor skills are present in sports activities. Explosive strength can be defined as the ability to produce maximum force as soon as possible, and it represents an essential factor in activities where it is necessary to increase the acceleration of the body mass, the mass of specific body parts, or of an external object. The aim of study – to determine the effects of an experimental program on the explosive strength of lower limbs in male adolescents.

Material and Methods One hundred and one male adolescent (aged 19 years ± 6 months; body height 181.43 ± 7.42 cm; body mass 80.08 ± 10.07 kg) were recruited and randomly divided into two groups: experimental group (E; N=48) and control group (K; N=48). The E group performed the experimental program which lasted fifteen weeks and consisted of three 60-min training sessions per week. All participants were tested on Squat Jump (SJ), Countermovement Jump (CMJ), Countermovement Jump with arms (CMJa) and Continuous Jump with Straight Legs (CJSL). The four tests were performed using a Kistler force platform to measure Quatro Jump Bosco Protocol Version 1.0.9.2 and gave us data about the jump height, number of jumps for 15s, average power jump and peak power jump. The multivariate analysis covariance (MANCOVA) and follow up analysis covariance (ANCOVA) were used to analyze the data.

Results The results of MANCOVA showed statistically significant differences ($p \leq 0.001$) between the E and K groups in all systems of variable lower limb explosive strength in male adolescents. In addition, results of ANCOVA showed statistically significant differences ($p \leq 0.001$) in SJ, CMJ, CMJa and CJSL in favor of the E group compared to the K one.

Conclusions The results of this research show that a fifteen-week experimental program can lead to significant improvements in lower limb explosive strength in male adolescents.

Keywords: plyometric training, complex training, motor abilities, adolescents

Introduction

Explosive strength can be defined as the ability to produce maximum force as soon as possible, and it represents an essential factor in activities where it is necessary to increase the acceleration of the body mass, the mass of specific body parts, or of an external object. The explosive strength is genetically determined, but his development can be influenced by the training process. In the adolescent period (from 10 to 24 years of age), explosive strength of the lower limbs can be developed, however, the training program has to be properly designed [1].

Verhoshanski & Tatyan [2] designed plyometric training and thus caused a revolution in methods for developing lower limb explosive strength. Since then, and until the present, there have been many studies that confirmed that plyometric training improves the explosive strength of the lower limbs of adolescents (athletes, non-athletes and recreational athletes). More precisely, Impellizzeri et al. [3] showed that 4 weeks of plyometric training improves the lower limb explosive strength in the form of jumps (squat jump and countermovement jump). While Ronnestad et al. [4] stated that a combination of plyometric training and specific strength training is also efficient in developing the explosive strength of the lower limbs of adolescents (athletes). Furthermore, Blattner & Noble [5] stated that isokinetic training can produce similar effects as plyometric training on the vertical jump of adolescent athletes. In addition, should not be neglected complex training which involve a combination of heavy and light loads, as well as that complex pair of exercises represents a good strategy for increasing explosive strength through increased neuromuscular activity [6].

Other studies state that plyometric training effectively affects the explosive strength of the limbs in adolescents [7, 8, 9, 10]. So Fischetti et al.

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[7] studied specific acute adaptation to vertical jump in boys aged 12–14 years. The authors concluded that adolescents may benefit more from exposure to a combination of plyometric and resistance training methods. Peitz et al. [8] noted that various types of resistance training (e.g., bodyweight, free weights) are effective in improving muscle strength (e.g., maximal voluntary contraction) in untrained children and adolescents. Singla et al. [9] studied the effect of plyometric training on neuromuscular adaptation in cricketers of different age groups. The authors note that adolescents under 18 years of age showed significantly greater improvements in upper body balance and upper body strength than adults aged 18–25 years. Flavio et al. [10] argue that 4 weeks of plyometric training is not enough to significantly improve vertical and horizontal jump speed and height for adolescents aged 14 to 17 years. The results of these studies are in good agreement with other studies involving adolescents [3, 4, 5].

Based on the above, it can be obtained that there are a number of different training methods that are applied in developing the lower limb explosive strength of adolescents (athletes, recreational athletes, and non-athletes), however, plyometric training is the most applicable one.

The research question is whether plyometric training will have better effects if it is combined with other training types, which include starting accelerations, running with loads, jumps with loads, and locomotor system stabilization exercises. Therefore, the aim of this study was to determine the effects of the experimental program on the explosive strength of the lower limbs of male adolescents.

Material and Methods

Participants

The sample of participants consisted of 101 male adolescents (age 20.03 ± 1.16 years; body height 181.43 ± 7.42 cm; body mass 80.08 ± 10.07 kg) from the student population of the University of Novi Sad. During the selection of respondents, 120 students were selected and tested at the initial measurement, however, after a fifteen-week treatment, there was a respondent dropout of 15.83% (19 respondents). Therefore, the study sample included 101 participants who fully implemented the experimental program and were present at the initial and final testing. The participants were randomly divided into two groups: experimental (E, n=48) and control (K, n=53) groups. The respondents from E group were subjected to a fifteen-week training program three times a week, while the subjects from the control group, in addition to their daily activities, voluntarily engaged in sports and recreational activities (football, basketball, volleyball, tennis, running...), 2-3 times a week, so it was a control treatment that was not programmed by the author. The testing procedures were performed following the ethical norms and standards laid down in the Declaration of Helsinki.

Research Design

Procedure

The measurement of lower limb explosive strength was performed before the experimental program, and after a period of 15 weeks. The testing was conducted at the Sports Center of the Faculty of Sport and Physical Education, Novi Sad from 8 A.M. to 3 P.M. in one day. The air temperature in the Sports Center ranged from 22 to 25°C. The respondents came in groups of 10 participants and they did a standard 15-minute warm-up before the testing. The testing session began with anthropometric measurements (body height and body weight). The participants were then instructed to assess the lower-body muscular strength (Squat Jump, Countermovement Jump, Countermovement Jump with Arms, and Continuous Jump with Straight Legs). The participants performed 3 trials for the tests, with a recovery of approximately 3 minutes between the trials. All tests were performed using the same measuring instrument i.e., a Kistler force platform (Quattro Jump, 9290, Switzerland). The initial and final testing was carried out under the same criteria so that the results could be compared [11]. The measurement was performed by assistants appointed at the Faculty of Sport and Physical Education.

Variables and testing

The Squat Jump (SJ), Countermovement Jump (CMJ), Countermovement Jump with Arms (CMJa) and Continuous Jump with Straight Legs (CJSL) were determined by a force platform (Kistler Instrument AG, Quattro Jump, 9290, Switzerland). This platform has a Bosco protocol [12], which objectively allows measurements of the following: high jump (cm), number of jumps for 15s (n), average jump power (W/kg) and peak power (W/kg). Each participant performed 3 trials of each jump and the best result was recorded for statistical analysis.

Experimental program

The experimental program was conducted over a period of 15 weeks (3 times a week - on Monday, Wednesday and Friday). The respondents were required to perform exercises at a technically high level during the entire experimental program, which enabled the respondents to avoid injuries, and the effects of the exercise to be raised to the maximum level. Four mesocycles represented the basis for the experimental program implementation.

In *the first mesocycle*, the implementation was focused on the development of basic abilities that should create the basis for the specific nature of the mesocycle that will follow after this period. The nature of the work in *the second mesocycle* was focused on the transition from basic to specific work. Special attention was paid to the introduction of specific exercises for the development of specific abilities.

The development of specific abilities was the basis of *the third mesocycle.* In the third mesocycle, exercises of a dynamic explosive nature were performed, which contributed to a further increase in the abilities and efficiency of the experimental program.

The fourth mesocycle focused on the implementation of exercises aimed at raising the abilities of a specific nature to the highest level.

Two-foot jumps were performed in the first five weeks (twice a week) in the volume of 60 jumps per training session, as well as in a combination of two-foot hurdle jumps and two-foot standing long jumps. In the other five weeks, two-foot jumps were performed twice a week (weeks 6, 8 and 9) and once a week (weeks 7 and 10). In the final three weeks of the experimental program, two-foot jumps were mostly carried out twice a week.

Single-leg jumps were performed once a week (in the first five weeks). In the other five weeks, single-leg jumps were performed twice a week (weeks 7 and 10) and once a week (weeks 6 and 9). In the final three weeks of the experimental program, the number of single-leg jumps increased to 2 times a week. Single-leg jumps were performed less often in the first 6 weeks (3 treatments during 6 weeks), and as the respondents' ability increased the number of training treatments also increased to 11 in the last 9 weeks. The total number of jumps per training session was increased to 80 in the second 5 weeks, and in the last 5 weeks, the participants achieved a volume of 100 jumps per training session. Alternate-foot jumps were performed in combination with two-foot jumps and single-leg jumps, whereby the dynamics of training from the 5th week until the end of the experimental program was carried out alternately with one training session per week (on odd-numbered weeks), while two training sessions were performed on even-numbered weeks. Horizontal and vertical jumps were done separately, and sometimes in combination. The jumps were combined in order to avoid motor stereotypes and to direct the dynamic force of an explosive striking nature forward and upwards. They were realized through jumps over the hurdles with a distance of 6-9 meters (vertical hurdle jump).

The horizontal jump between the hurdles should have been performed in 2-3 jumps, depending on the length of the distance.

Resistance jumping exercises were performed in a smaller volume due to the complexity and difficulty of the performance. They were realized by the respondents' performing jumps with a vest of adequate weight (2-10 kg, depending on their body mass; 2% at the beginning of the experimental program, and up to 10% at the end of the program). Resistance jumping exercises served as basic preparation (in the first 5 weeks) for plyometric jumping exercises. In the first 5 weeks, plyometric jumps were performed only in the 4th week, and in the second 5-week period, the number of plyometric training sessions was increased to 5 training sessions, and to 7 training sessions in the last 5 weeks. Plyometric training sessions were realized through jump-offs and landings from jump boxes of adequate height (in the first 5 weeks the height was 60 cm, in the second 5 weeks it was 80 cm and in the last 5 weeks it was 100 cm). After the landing, the respondents mostly performed two-foot jumps over the hurdle, which was also lower in height (76 cm) in the first 5 weeks, and with a gradual increase, it reached a height of 100 cm by the end of the treatment.

Exercises that include starting accelerations were used as a means to improve the technique and coordination of the performance of the assigned exercises and the number of training sessions was gradually decreased during the experimental program.

Between the 2nd and the 11th week, exercises that include resistance running activities were performed. This was realized by running uphill at a distance of 50-200m. The locomotor system stabilization exercises were performed during the entire experimental program, with special reference to the stabilization of the ankle joint, knee joint, pelvis and spine, as the pillar of the entire locomotor apparatus.

As the last, but not the least important type of activity, general physical preparation was done during the experimental program. The target muscle groups included the abdominal muscles, back muscles, and the muscles of the arms and shoulder girdle. The objective of this activity was to strengthen these muscle groups through the implementation of as many different ways of performance as possible. The intensity and volume of work during the experimental program were designed according to Malacko [13].

A schematic representation of the plan of the experimental program can be seen in Table 1.

Statistical analysis

Statistical analyses were performed with SPSS software (Version 20.0; IBM SPSS, Inc., Chicago, IL, USA). Arithmetic mean (Mean) and standard deviation (SD) were calculated for all variables. To determine the effect of the applied experimental treatment (training model), a multivariate analysis of covariance (MANCOVA) was applied for the entire system of applied variables, while individual differences in the analyzed variables were determined by the application of a univariate analysis of covariance (ANCOVA).

Table 1. Plan of the 15-week experimental program

WEEK TYPE OF ACTIVITY	**I** **1 2** **3**	**II** **1 2** **3**	**III** **1 2** **3**	**IV** **1 2** **3**	**V** **1 2** **3**	**VI** **1 2** **3**	**VII** **1 2** **3**	**VIII** **1 2** **3**	**IX** **1 2** **3**	**X** **1 2** **3**	**XI** **1 2** **3**	**XII** **1 2** **3**	**XIII** **1 2** **3**	**XIV** **1 2** **3**	**XV** **1 2** **3**
Two-foot jumps	x x	x x	x x	x x	x x	x x	x	x x	x x	x	x x	x x	x	x x	x
Single leg jumps			x		x	x	x x		x	x x	x		x x	x	x x
Alternate foot jumps	x x	x	x	x	x	x	x x	x	x	x x	x	x	x x	x	x x
Horizontal jumps	x x	x	x	x	x	x	x x	x	x	x x	x	x	x x	x	x x
Vertical jumps	x x	x x	x x	x	x x	x x	x	x	x x	x	x x	x	x	x x	x
Combination of horizontal and vertical jumps		x	x		x x	x x	x		x x	x	x x		x	x x	x
Resistance jumping exercise	x x	x	x		x x	x	x x		x	x x	x		x x	x	x
Plyometric exercise				x		x	x	x	x	x	x x	x	x	x x	x
Starting accelerations	x x x	x	x x	x x x	x	x	x x	x x x	x	x x	x x	x x x	x	x x	x
Resistance running exercise		x x	x		x x	x x	x		x x	x	x x				
Locomotor system stabilization exercise	x x	x	x x	x x x	x	x x	x	x x x	x x	x	x x	x x x	x	x x	x
General physical preparation	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x	x x x

Abbreviation: 1 – Monday; 2 – Wednesday; 3 - Friday

Results

Table 2 presents the results of the MANCOVA showing us that there is a statistically significant difference (P=0.000) between the E and K groups in the entire system of variables of the lower limb explosive strength. Regarding the individual inspections of the variables in Table 2, it can be shown that a statistically significant difference (p=0.000) between the groups (E vs. K) in all variables: SJ (cm); CMJ (cm); CMJa (cm); CJSL (cm); CJSL (n); CJSL average power (W/kg) and CJSL peak power (W/kg).

Table 3 shows the corrected means as well as the confidence intervals of the individual variables of the explosive strength of the lower limbs after the treatment. The fact that the confidence interval contains zero in none of the variables leads to the conclusion that there is a difference between the E and K groups of respondents: SJ (cm) (3.17 / 4.27), CMJ (cm) (3.34 / 4.15), CMJa (cm) (1.22 / 2.41), CJSLn (n) (1.45 / 2.30), CJSL (cm) (3.18 / 3.76), CJSL peak power (W/kg) (3.35 / 4.52) and CJSL average power (W/kg) (3.42 / 4.26). Also, inspecting the results presented in Table 3 of the corrected means of the analyzed variables, it can be concluded that the E group had higher values of the variables compared to the K group and that the experimental program was successful.

Discussion

Each training process, as well as our experimental program, must be an organized and planned time-limited process, including constantly changing cycles. The end result expected is that the body is transformed and transferred from the initial condition to a new final one. Therefore, the aim of this study was to determine the effects of the experimental program on the explosive strength of the lower limbs of male adolescents. The main findings of the study show that a 15-week experimental program improves the lower limb explosive strength in adolescent males.

The results of this study show that there is a significant difference between the E and K groups in all variables of the lower limb explosive strength (p= 0.000) in favor of the E group. The variables of the explosive strength of the lower limbs were obtained by testing different types of jumps, whereby the height of the jump, the peak power of the jump, the average power of the jump, the number of jumps, etc. were taken into account. The results of the corrected means and the confidence intervals indicate that all differences in the progress of the lower limb explosive strength were determined in favor of the

Table 2. Difference between the E and K groups in the variables of lower limb explosive strength after the treatments applied

Variables	E (Mean±SD)		Δ (%)	K (Mean±SD)		Δ (%)	F*	p
	Initial	Final		Initial	Final			
SJ (cm)	43.23±4.34	47.03±4.57	8.79	44.02±4.41	43.85±3.73	-0.39	170.00	0.000*
CMJ (cm)	46.87±4.77	50.52±4.93	7.79	47.72±4.89	47.70±5.44	-0.04	275.79	0.000*
CMJa (cm)	54.50±6.36	58.67±5.92	7.65	53.81±4.22	56.35±4.58	4.72	33.34	0.000*
CJSL (cm)	36.75±3.70	40.36±3.72	9.82	37.67±3.50	37.55±3.73	-0.32	57.85	0.000*
CJSLn (n)	19.48±1.75	21.50±1.57	10.37	19.34±2.09	19.53±2.23	0.98	61.51	0.000*
CJSL average power (W/kg)	40.72±5.82	44.80±5.98	10.02	41.22±5.31	41.35±5.27	0.32	287.62	0.000*
CJSL peak power (W/kg)	46.61±6.94	51.39±6.04	10.26	47.82±5.71	48.32±4.85	1.05	167.63	0.000*

F= 167.763; p=0.000

Abbreviation: E – experimental group; K – control group; SJ – squat jump; CMJ – countermovement jump; CMJa - countermovement jump with arm swing; CJSL – continuous jumps with straight legs, average jump height; CJSLn - number of continuous jumps with straight legs; CJSL average power – continuous jumps with straight legs, average power; CJSL peak power – continuous jumps with straight legs, maximum jump power; F* – test for univariate analysis of covariance, * – statistically significant difference between the groups within one variable (ANCOVA) ($p \leqslant 0.000$); Δ% = individual progress in percentage; F – test for multivariate analysis of covariance, P – level of significance of differences between the groups in the system of variables ($p \leqslant 0.000$).

Table 3. Corrected means and confidence intervals of the E and K groups in the variables of lower limb explosive strength after the treatments applied

Groups		Variable	Corrected means		Confidence interval	
E	K	SJ (cm)	47.31	43.59	3.17	4.27
E	K	CMJ (sm)	51.01	47.26	3.34	4.15
E	K	CMJa (cm)	58.39	56.57	1.22	2.41
E	K	CJSLn (n)	21.45	19.57	1.45	2.30
E	K	CJSL (cm)	40.73	37.26	3.18	3.76
E	K	CJSL average power (W/kg)	51.87	47.93	3.35	4.52
E	K	CJSL peak power (W/kg)	45.02	41.18	3.42	4.26

Abbreviation: E – experimental group, K – control group

E group, which leads us to the conclusion that the experimental program influenced the explosive strength of the lower limbs to develop significantly. All the levels of significance of the differences found in this system of explosive strength are very high (p= .000), which can lead us to the conclusion that the two groups were significantly different. The K group had no programmed treatment but it included the respondents who, in addition to daily life activities, only engage in low-intensity recreational activities. On the other hand, the experimental program lasted for an entire mesocycle (15 weeks), which, in the training process, is quite enough to achieve significant effects regarding the development of motor skills that are not innate to a large extent. The results of this study are in accordance with the research of [10] where we can find that the respondents increased the peak power of the jump, vertical jump, speed, and agility after the two-month treatment applied. Also, Kobal et al. [14] showed that vertical jump (CMJ height) increases regardless of the training scheme (complex training, traditional training, contrast training, training with loads – plyometric alternately). It has been assumed that rapid improvements in vertical jump ability occur due to short-term neuromuscular adaptations induced by all training regimens [9, 15]. In fact, some studies have already reported that improvement in vertical jump ability is accompanied by an increase in peak power of the jump [7, 16, 17, 18]. The maximum increase in jump power amounted to approximately 50%, which is higher than the values previously reported in the literature, using isolated regimens of strength training [19] and plyometric training [20]. Accordingly, Villarrel et al., [21] concluded that improvements in lower limb explosive strength are significantly greater when plyometric exercises are performed in conjunction with strength training, which has been confirmed by [22]. The authors [22] stated that strength training combined with weights and plyometric exercises has the greatest impact on the explosive strength of the lower limbs. According to these authors, this combination may optimize neuromechanical factors that can improve maximum strength performance, due to the possible summation of training adaptations (provided by both strength training and plyometric training) to neuromuscular performance. In the study conducted by [21], young football players were trained at 70% 1RM (on average during all 8 weeks), which can be considered high-intensity training. It should be noted that the range of loads used herein (i.e., 60–80% 1RM) was chosen in accordance with the recommendations given in a specific meta-analysis, which highlighted that this training intensity is capable of enhancing the acute neuromuscular responses induced by PAP [23]. Also, a combination of strength training and plyometric exercises has been shown to be effective for improving sport-specific performance. However, there is no consensus on the most effective way to combine these methods in the same training session in order to achieve greater improvements in neuromuscular performance. Therefore, new research is always welcome. And this study has shown that if plyometric exercises, starting acceleration exercises and stabilization exercises are performed during one training session, the explosive strength of the lower limbs of adolescent males can be significantly improved. This research is a novelty compared to other studies. In other studies, [19, 21], exercises with loads and plyometric exercises were performed during one training session, whereas in this study plyometric exercises, acceleration exercises and exercises for the development of body stabilization were performed during one training session. Therefore, a combination of plyometric exercises with stabilization exercises and acceleration exercises can significantly improve the lower limb explosive strength in adolescent males.

Conclusions

It can be concluded that this carefully planned 15-week experimental program, which includes plyometric exercises, resistance jumping exercise, exercises for the development of acceleration and stabilization exercises, was very successful for the development of explosive strength of the lower limbs in respect of the given sample of respondents (adolescents). During the implementation of the experimental program, all principles of the training process and its periodization were respected.

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