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Original research article

EFFECTS OF VIBRATION AND ISOMETRIC TRAINING ON THE EXPLOSIVE STRENGTH OF THE LOWER LIMBS

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Abstract. *The aim of this research was to determine the effects of two 10-week training programs on the change in explosive strength parameters, as well as to determine whether possible effects were caused by the vibration stimulation of the muscles or isometric training. The research sample comprised 60 male participants, aged 21 ± 6 months, randomly divided into three subsamples: the first experimental group (n=15) comprised participants included in a specially designed low frequency vibration training with the Flexi-bar; the second experimental group (n=15) comprised participants included in specially designed isometric training; and the third, control group, comprised participants not included in any specially designed training program (n=30). All of the participants were tested at the beginning and the end of the experimental program by an explosive strength estimation test on a tensiometric platform. The statistical methods applied in this research to investigate the effects of the training were the univariate analysis of covariance (ANCOVA), and the multivariate analysis of covariance (MANCOVA). By analyzing the obtained results, it was determined that neither vibration training with the Flexi-bar nor isometric training exhibited a statistically significant influence on the change in the explosive strength values of the lower limbs, but that there were changes in the mean values of the observed parameters. Measurements of the explosive strength parameters of the upper limbs and the parameters of the explosive strength of the lower limbs were administered in all three groups of participants. The experimental program did not yield the expected results, but points to further research which should investigate the effects of the vibration stimulation of muscles by the Flexi-bar, applying some different exercises, as well as the investigation of the effects on other types of strength.*

Key words: *Flexi-bar, static exercises, counter movement jump.*

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INTRODUCTION

Explosive strength implies all the movements when an athlete is short of time to develop maximal power, but uses the shortest possible time to act on the apparatus or the surface, aiming at achieving the best result. This motor ability represents one of the determinants of success in all activities, demanding an exertion of muscle power in the shortest time interval (Newton & Kreamer, 1994). The exerted explosive strength depends on the percentage and the composition of the given muscle group motor units (Branković & Bubanj, 1997). One of the manifestations of the explosive strength of the lower limbs is the vertical jump(s), which is defined as an individual capability of the neuro-muscular system of the participants to exert muscle effort in the shortest time interval (Verhošanski, 1979). As the final test output one is provided with numeric values which are then used for the estimation of the participants' explosive strength (Marković & Gregov, 2005). Nowadays, physicians and physiotherapists use numerous instruments to determine muscle power (Fan et al., 2010; Hairi et al., 2010; Conroy et al., 2012). The most frequently used among them, a valid and reliable instrument, was also used in this research, the tensiometric platform.

In order to achieve the best explosive strength values, coaches have at their disposal a large number of possibilities: jumps, free weights, exercise equipment, walking with a load, etc. Training to develop muscle strength can be divided into two groups: training with different types of muscle contractions and training with combined muscle contractions. Isometric training is one way to develop muscle strength with different muscle contractions, while vibration training falls under the type of training used to develop muscular strength with combined muscle contractions (Radovanović & Ignjatović, 2009).

Application of vibration stimulation for medical purposes originated at the end of the nineteenth century, when Dr. *John Harvey Kellogg* started using vibrating chairs as part of a program of hospital treatment (Calvert, 2002). In former East Germany, Dr. *Biermann* conducted experiments that studied the effects of vibration massage and he described those vibration as "cyclical vibrations" with which to improve the general condition of the joints (Biermann, 1960). In the 1970s, in the former Soviet Union, people recognized the potential of vibration stimulation in the space program used to prevent negative impacts of antigravity on the reduction of muscle function and bone mineral density (Golecki et al., 2012), as well as their use in sport which led to the development of the vibration system of training for the Olympic Team.

Research shows that the use of vibration training in sport contributes to improving jump height, strength and flexibility, reducing the percentage of injuries (Nazarov & Spivak, 1985; Kunnemeyer & Schmidtbleicher, 1997). The human body exposed to vibration stimuli responds with a reflexive muscle contraction (Babajić, Bradić, Pojskić, Kovačević & Abazović, 2013). Studies showed that vibration exercises cause increased EMG activity of the muscles, where the muscle spindle plays an important role in the enhancement of muscle activation. From the neurological aspect, such as the involvement of motor units, synchronization and contraction may be responsible for the increase in power and torque after exercising. Other mechanisms of vibration, such as the heat effect, wherein the friction between the vibrating tissues may result in an increase in the temperature of the muscle, along with the increase in blood flow to the muscle, can contribute to the improvement of muscle flexibility (Matthew, Stephen, David & Walter, 2005; Issurin & Tenenbaum, 1999).

The effect of vibration depends largely on the application site, orientation, duration and intensity of the vibrations (Zatsiorsky & Kraemer, 2009). The *Flexi-bar* is a prop for the exercise, within vibration training, designed by a German physiotherapist. It is made of an artificial material (special, reinforced glass thread), which was used in the research on flying and space flying. The grip located in the middle of the rod and the improvised weights that are placed on the ends are made of rubber. The principle of the *Flexi-bar* is that when its sweeping vibration frequency of 4.6 Hz is produced, it is then transferred to the body through the grips, along the arm and shoulder (*Flexi-Sports, Bislez, Stroud, United Kingdom, 514 g weight, 1520 mm in length).*

Isometric training had the greatest application in the sixties; it owes its popularity to two German researchers T. Hettinger and E. Muller (Hettinger & Muller, 1953). The effect of isometric exercises significantly increases with the application within the circuit training that is defined by Morgan & Adamson (1959). The application of isometric training means the application of several exercises. Of course, this does not imply a combination of concentric and eccentric contractions during this type of training. The very outcome of the exercises is the same, i.e. there is no movement (Siff & Verkhoshansky, 1999; Thibaudeau, 2007; Bompa, 2009). The results of most studies claim positive effects of the isometric training only in a trained position, but some researchers have noted a certain positive transfer that shows the effects of this training in untrained positions as well (Thepaut-Mathieu, Van Hoecke & Martin, 1988; Knapik, Mawdsley & Ramos, 1983). O'Shea & O'Shea (1989) in their work have proved a positive effect of the isometric training on the increase in explosive leg strength (vertical jumps).

The aim of this study was to determine the effects of the application of the two training programs over a period of 10 weeks on the change in explosive strength parameters, as well as to determine whether any effects were caused by the vibration stimulation of muscles or isometric training.

THE METHOD

Total sample of participants in this research was comprised of the students of the Faculty of Sport and Physical Education, University of Niš. The participants were selected under the condition that none of them were involved in any programmed training process apart from their regular physical activities included in the faculty curricula courses. The total research sample comprised 60 male subjects, aged 21 ± 6 months, randomly divided into three subsamples. The first experimental group (n=15) comprised participants who took part in a specially designed low frequency vibration training with the *Flexi-bar*, body height 177,06 ± 7,62 cm, body mass 73,91 ± 9,30 kg cm, (mean value ± standard deviation). The second experimental group (n=15) comprised participants who took part in a specially designed isometric training containing the same exercises as the vibration training but without the additional vibration stimulation using the *Flexi-bar*, body height 174,07 ± 5,31 cm, body mass 72,51 ± 10,12 kg cm, (mean value ± standard deviation). The third group was a control group (n=30) which comprised participants performing only regular daily physical activities included in the faculty curricula, body height 181,37 ± 7,23 cm, body mass 77,19 ± 7,99 kg cm, (mean value ± standard deviation). The anthropometric characteristics of the participants were measured in the following manner: body height was measured with a precision of 0,1 cm (anthropometer by Martin) and body mass was measured with a precision of 0,1 kg (Tanita BWB800, Japan). The participants voluntarily agreed to participate in the study which was conducted in accordance with the Helsinki Declaration.

Equipment for the estimation of the explosive strength of the lower limbs consists of a movable tensiometric platform on which different types of jumps are performed. The tensiometric platform is manufactured by the TRCpro Company (Novi Sad, Serbia) and is composed of German HBM type sensors. The tensiometric platform dimensions are 1000×1000 mm. The testing objects on the platform are different types of vertical jumps, which are afterwards analyzed by a computer, i.e. Catman® software, an adequate and professional software for the acquisition, visualization and processing of the measured values. In contrast to other methods for the estimation of the vertical jumping ability parameters, the tensiometric platform measures the very segment which is of vital interest – jumping force in relation to time. The estimation of the explosive strength of the lower limbs on the tensiometric platform was aptly researched my numerous authors. Doctor Carmelo Bosco is one of the most distinguished researchers in this area, the tensiometric platform, and has investigated a response of the leg skeletal muscles after one vibration training (Bosco, Cardinale & Tsarpela, 1999), after a 10-day treatment (Bosco et al., 1998). In order to objectively measure the force and time interval during the vertical jumps Kistler, along with Dr. Bosco, developed the Quattro Jump Bosco Protocol (Bosco, 1997). The Bosco protocol describes several tests, but one of the most comprehensive is the counter movement jump (CMJ) test (Cormie, Deane, Triplett & McBride, 2006; Paradisis & Zacharogiannis, 2007). The same test was used in this research. The following variables were monitored: maximum (peak) of the eccentric contraction force (N), eccentric contraction time (s), maximum (peak) of the concentric contraction force (N), concentric contraction time (s) and explosive strength index (N/s).

The experimental program lasted for 10 weeks, the initial measurement was performed before the start of the program, and the final measurement was performed at the end of the program. The experimental program comprised 20 trainings. Strength training was devised by the researchers themselves respecting all the recommendations of the *Flexi-bar* manufacturers, as well as the recommendations of the leading authors investigating this topic (Zatsiorsky, Kraemer, 2009; Verkoshansky, 1979; Bompa, 2009; Thibaudeau, 2007). Both experimental group participants performed the same isometric exercises with the same duration, wherein the vibration training participants coupled the exercises with the vibration muscle stimulation produced by the *Flexi-bar.* Training was divided into three basic parts: the warm up, main part and cooling down. Static exercises which made up the basic part of the training were the following: the half squat, squat, step out and the bridge. Each exercise was performed three times for a duration of *20* seconds after repetition in the first five weeks, and then the training volume was increased to 30 seconds after repetition in the last five weeks. After each repetition, there was a relaxation time of 20 to 30 seconds, and optimal relaxation time of 60 to 90 seconds upon the finished set. The intensity of the exercising was determined by the participant's weight.

Statistical analyses were performed using descriptive statistics, the univariate analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA) so as to investigate the effects of the training on the final measurement by comparing all the groups mutually. Statistical significance was determined at $p<0,05$. All of the data were processed by means of the statistical package SPSS 11.0 (SPSS, Chicago, IL).

RESULTS

The results of the mean values of the variables for the explosive strength of the lower limbs: peak of the eccentric contraction force, eccentric contraction time, peak of the concentric contraction force, concentric contraction time and explosive strength index) obtained by the CMJ test between the first experimental group (*n*=15), the second experimental group (*n*=15) and the control group (*n*=30) between the initial and final measuring are given in Table 1. By analyzing the obtained results, it can be concluded that the mean value was improved in the final measuring in comparison to the initial measuring for all the variables in all three groups.

Table 1 Descriptive statistical parameters for the groups at the initial and final measuring

Variable (unit)	Measuring	First experimental group		Second experimental group		Control group	
		Mean	SD	Mean	SD	Mean	SD
Eccentric contraction force peak (N)	Initial	531,88	134,69	546,69	125,61	611,41	144,21
	Final	593,35	137,41	585,75	105,64	614,27	123,52
Eccentric contraction time (s)	Initial	,20	,05	,15	,04	,16	,05
	Final	,15	,04	,16	,04	,15	,03
Concentric contraction force peak (N)	Initial	1674,63	234,89	1821,78	390,50	1950,39	354,30
	Final	1812,04	435,05	1853,83	376,99	2100,09	430,52
Concentric contraction time (s)	Initial	,45	,28	,27	,05	,27	,07
	Final	,27	,07	,25	,04	,25	,06
Explosive strength index (N/s)	Initial	6103,97	1317,27	7152,40	2994,17	8002,53	4657,42
	Final	7560,01	4261,88	7857,61	3540,48	9218,13	4556,28

Tables 2, 3, and 4 show the results of the multivariate analysis of covariance (*MANCOVA*) which assesses the effects of the experimental program on the values for the explosive strength of the lower limbs obtained by the CMJ test for all three groups of participants. The results in the Tables present the comparison of two groups each time. Table 2 shows the results of the first and the second experimental group. Table 3 shows the results of the first experimental group and the control group. Table 4 shows the results of the second experimental group and the control group.

Table 2 Results of the multivariate analysis of covariance (MANCOVA) between the participants of the first experimental group (n=15) and the second experimental group (n=15)

Variable	Wilks' Lambda	F	Sig.
Experimental program	0,73	1,39	0,273

Table 3 Results of the multivariate analysis of covariance (MANCOVA) between the participants of the first experimental group (n=15) and the control group (n=30)

Variable	Wilks' Lambda	F	Sig.
Experimental program	0,81	1,64	0,177

Table 4 Results of the multivariate analysis of covariance (MANCOVA) between the participants of the second experimental group (n=15) and the control group (n=30)

Variable	Wilks' Lambda	F	Sig.
Experimental program	0,78	1,89	0,123

The obtained results lead us to a conclusion that the effects of the experimental program on the studied participants do not show a statistically significant difference. The experimental program does not exhibit statistically significant effects on the change of the values for the explosive strength of the lower limbs for the participants of the first and the second experimental group (sig=0,273), the first experimental and the control group (sig=0,177), the second experimental and the control group (sig=0,123).

Tables 5, 6, and 7 show the results of the univariate analysis of covariance (*ANCOVA*) which assesses the effects of the experimental program on the values for the explosive strength of the lower limbs obtained by the CMJ test for all three groups of participants. The results in the Tables present the comparison of two groups each time. Table 5 shows the results of the first and the second experimental group. Table 6 shows the results of the first experimental group and the control group. Table 7 shows the results of the second experimental group and the control group.

Table 5 Results of the univariate analysis of covariance (ANCOVA) between the participants of the first experimental group (n=15) and the second experimental group (n=15)

Variable (unit)	F	Sig.
Eccentric contraction force peak (N)	0,10	0,752
Eccentric contraction time (s)	1,01	0,323
Concentric contraction force peak (N)	0,16	0,695
Concentric contraction time (s)	0,86	0,362
Explosive strength index (N/s)	0,01	0,944

Table 6 Results of the univariate analysis of covariance (ANCOVA) between the participants of the first experimental group (n=15) and the control group (n=30)

Variable (unit)	F	Sig.
Eccentric contraction force peak (N)	0,13	0,724
Eccentric contraction time (s)	0,00	0,963
Concentric contraction force peak (N)	1,55	0,219
Concentric contraction time (s)	0,82	0,371
Explosive strength index (N/s)	1,15	0,289

Table 7 Results of the univariate analysis of covariance (ANCOVA) between the participants of the second experimental group (n=15) and the control group (n=30)

Variable (unit)	F	Sig.
Eccentric contraction force peak (N)	0,05	0,831
Eccentric contraction time (s)	1,68	0,202
Concentric contraction force peak (N)	2,32	0,135
Concentric contraction time (s)	0,00	0,962
Explosive strength index (N/s)	0,82	0,369

On the basis of the obtained statistical significances, one can conclude that there are no differences between the studied groups of participants. The experimental program does not exhibit any statistically significant effect on any of the studied values for the explosive strength of the lower limbs, taking into account all three groups of participants.

DISCUSSION

The effects of the vibration training application (upon several weeks of persistent training) on explosive strength were demonstrated in many studies, whether they investigated jump height, stamina in explosive strength or mechanical power (Bosco et al., 1998; Paradisis & Zacharogiannis 2007; Torvinen et al., 2002). These studies show the positive effects of applying different exercises on the vibratory platform as opposed to the same exercises that are performed without the platform. Considering what frequency causes the best effects in the CMJ test, the results suggest that training at a frequency of 50 Hz gives a much better effect than training at a lower frequency than 30 Hz (Lamont, Bemben, Cramer, Gayaud & Acree, 2006).

Acute effects of the vibration training show improved results on the CMJ test, but which training protocol would best influence sports performance is still being investigated (Cormie et al., 2006). The effects of vibration training are transient, but it is recommended as an excellent way to prepare the locomotor apparatus for the upcoming muscle strains (Bazett-Jones, Finch & Dugan, 2008; Obradović, Madić & Pantović, 2010).

Research on the effects of vibration training shows that it has a positive effect on strength and that the same exercises applied without vibration stimulation in static conditions (isometric training) do not give the same results. The results of this study indicate that vibration training does not give statistically significant effects on any of the analyzed values for the explosive strength of the lower limbs. The reason could be the insufficient frequency of 4.6 Hz produced by the *Flexi-bar*, because to activate the muscles most effectively, the frequency should be in the range of 30 to 50 Hz (Luo, McNamara & Moran, 2005). It should also be noted that the vibrations to the lower limbs muscles were applied indirectly, which in turn can influence the effects of the vibration training (Luo et al., 2005). Static exercises comprising both types of training (vibration and isometric) have their own specificity in terms of the angle at which exercise is performed, because the nervous system is responsible for the specificity of the angle at which the isometric training is performed, and there is no increase in strength of the lower limbs in the other angles (Kitai & Sale, 1989).

Research conducted by Hawkey, Lau & Nevill (2009) aimed to examine the effect of six-week vibration training of the basketball players on their vertical jump. The results did not show any improvements in jump performance after exposure to the muscle vibration stimulation. As possible reasons, one mentions differences in training protocols, test equipment and the skills and experience of the participants. The results of similar studies corroborate this one, in fact, there were no statistically significant differences between the group that was subjected to the vibration training, when compared to the control group, which was not included in the training process, nor was doing the same static exercises without vibration stimulation, while being tested on lower limbs strength by the CMJ test (Cochrane, Legg & Hooker, 2004; Ruiter, Raak, Schilperoort, Holllander & Haan, 2003).

In a review study, Nordlund & Thorstensson (2007) concluded that the effects of vibration training on jumping performance were minimal or nonexistent, reaching this conclusion by comparing the same training with and without vibration stimulation. The results do not provide any basis for recommending vibration training as a replacement or supplement to traditional training in the gym, at least not for healthy people. Comparing the effects of vibration and traditional training, an improvement was noted in strength training after a training process in both cases (Schlumberger, Salin & Schmidtbleicher, 2001). Thus, it can be concluded that strength training with additional vibration stimulation is not superior to traditional training methods.

Conclusion

The impact of these types of training on motor abilities, as well as on strength as one of the most frequently studied areas, have not been extensively explored. In particular, this refers to vibration training with low frequency, as with the *Flexi-bar*. The exercises that are performed during this type of training are of the isometric type, and rightfully there are doubts as to whether the achieved effects are the product of the vibration or isometric training, and whether the frequency of 4.6 Hz is sufficient to achieve adequate muscle stimulation. The analysis of the obtained results shows that the use of vibration training with the *Flexi-bar* and the use of isometric training do not change the values of the explosive strength of the lower limbs. This means that the applied isometric exercises, as well as the vibration muscle stimulation at 4.6 Hz, do not produce the expected effects. The experimental program does not give the expected results in specific tests, but gives the possibility for new research to examine the effects of muscle vibration stimulation by the *Flexi-bar*, using different exercises, as well as a chance to explore the effects on other types of strength.

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EFEKTI VIBRACIONOG I IZOMETRISKOG TRENINGA NA EKSPLOZIVNU SNAGU DONJIH EKSTREMITETA

Cilj ovog istraživanja bio je da se utvrde efekti dva programa treninga u trajanju od 10 nedelja na promenu parametara eksplozivne snage, kao i da se utvrdi da li su eventualni efekti izazvani vibracionom stimulacijom mišića ili izometrijskim treningom. Ukupan uzorak ispitanika u ovom istraživanju sačinjavalo je 60 muškaraca, starosti 21 godina ± 6 meseci, nasumično raspoređenih u tri subuzorka. Prvu eksperimentalnu grupu (n=15) činili su ispitanici koji su bili uključeni u posebno programirani vibracioni trening niskih frekvencija sa Flexi-bar-om, drugu eksperimentalnu grupu (n=15) činili su ispitanici koji su bili uključeni u posebno programirani izometrijski trening i treća, kontrolna grupa, koju su činili ispitanici koji nisu bili uključeni ni u jedan programirani trening (n=30). Ispitanici su testirani na početku i na kraju eksperimentalnog programa testom za procenu eksplozivne snage na tenziometrijskoj platformi. Statističke metode koje su korišćene u ovom radu sa ciljem utvrđivanja efekata treninga bile su univarijantna analiza kovarijanse (ANCOVA) i multivarijantna analiza kovarijanse (MANCOVA). Analizom dobijenih rezultata utvrđeno je da ni vibracioni trening sa Flexi-bar-om, ni izometrijski trening ne utiču statistički značajno na promenu vrednosti eksploziivne snage donjih ekstremiteta, ali da dolazi do promena srednjih vrednosti posmatranih parametara. Eksperimentalni program ne daje očekivane rezultate, ali daje mogućnost za nova istraživanja kako bi se ispitali efekti vibracione stimulacije mišića Flexi-bar-om primenom drugačijih vežbi, kao i istraživanje efekata na druge tipove snage.

Ključne reči: *Flexi-bar, statičke vežbe, countermovement jump.*