THE EFFECTS OF 12-WEEK ISOKINETIC TRAINING ON KNEE STABILIZERS STRENGTH AND THE EFFICIENCY OF THE PERFORMANCE OF GYMNASTICS VAULTS

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Abstract

The aim of the research was to examine the effects of isokinetic training on knee stabilizer muscles strength, and whether this increases the efficiency of performing basic gymnastic vaults. A total of 60 respondents, students of the Faculty of Sports and Physical Education (average age 19.7±1.5 years, weight 75.3±2.9 kg, height 179.8±6.7 cm) were included. The subjects were divided into two groups, experimental (EG) (n=30) and control (CG) (n=30). As part of the 12-week program, the experimental group (EG) in addition to exercises within the regular classes at the university had an additional concentric isokinetic training 3 times a week on the Biodex System 3 dynamometer, while the control group (CG) only had exercises within the regular classes at the university. The results indicated statistically significant differences (p < 0.05) between EG and CG, both in increasing the knee stabilizer muscles strength and in the performance of gymnastic vaults in favor of EG. It can be concluded that the additional isokinetic training resulted in a greater increase in strength, but also a better performance of gymnastic vaults. The results of the research can be used as guidelines for planning and programming isokinetic strength training of knee stabilizer muscles, which will contribute to a better performance of gymnastic vaults. Since there is a small amount of research on the topic of this work, this study represents a good foundation and basis for some future research on the effects of isokinetic training in sports gymnastics.

Keywords: *artistic gymnastics, isokinetic, vaulting, muscular strength.*

INTRODUCTION

Artistic gymnastics is a closed-skill, multi-discipline sport performed on six and four apparatus by men and women, respectively (Gröpel & Beckmann, 2017). Gröpel and Beckmann (2017) stated that, according to the authors Cogan and Vidmar (2000), sports gymnastics consists of high demands, flexibility, courage, precision, balance, and artistic creativity. One of the most important ways in which a gymnast can distinguish his performance from others is the height of the flight, such as the height achieved on the vault, as this can indirectly affect the scoring by the judges (Prassas et al., 2006).

Vaulting is a gymnastics discipline characterized by a run towards the springboard, where competitors perform various acrobatic elements after take-off in the air, before landing on their feet (Bradshaw et al., 2010). Vaults are based on a complex movement structure and intense physical effort that is achieved in a short period and require highly developed speed, agility, and muscle strength from gymnasts (Kochanowicz et al., 2016). Of all the ways of performing vaults (handspring vaults, Tsukahara vaults, Yurchenko vaults), handspring vaults generally achieve the highest speed during the run-up phase (Schärer et al., 2021).

Vaulting is a dynamic activity performed in both men's and women's artistic gymnastics. Success in vaulting depends on a multitude of variables, some independent and some within the gymnast's control. Each vault and group of vaults has a different time structure. Vault can be divided into 7 phases. Some vaults require a faster run, some slower, some vaults have a long first flight phase, some have a short one, etc. In the competition, gymnasts perform the most difficult vault in their knowledge, which can be safely performed. As is shown in Figures 1 and 2, each vault in the Code of Points (CoP) can be divided into seven phases: (1) running, (2) jump on springboard, (3) springboard support and push phase, (4) first flight phase (1stfp), (5) support and push on the table, (6) second flight phase (2ndfp), and (7) landing (Atiković & Smajlović, 2011; Čuk & Karacsony, 2004; Ferkolj, 2010; Prassas & Gianikellis, 2002; Prassas et al., 2006; Takei, 2007).

There is no significant number of studies that investigated the effects of isokinetic training on the knee stabilizer muscles strength and the efficiency of performing gymnastic vaults; hence, in this research, other studies were used that had similar problems.

A high level of gymnast's entire body strength is required for successful performance of the demanding technical gymnastic elements. Numerous authors agree that a prerequisite for proper learning of technical movements is a high level of strength, while a low level of strength negatively affects the development of technical skills (Brown et al., 2007). Strength adaptation is sport-specific and an athlete's specialization and training determine the muscle groups where the adaptations occur (Seger & Thorstensson, 2000).

Training on isokinetic machines has proven to be the best solution, due to the optimal training load potential and continuous resistance (Cools et al., 2007; Teng et al., 2008). It has been shown that isokinetic strength training is relatively safe since once the movement is stopped the resistance is removed (De Ste Croix et al., 2009). To quantify a muscle group's ability to generate torque or force, isokinetic training may be used, and it is also useful as an exercise modality in the restoration of a muscle group's pre-injury level of strength (Rochcongar, 2004).

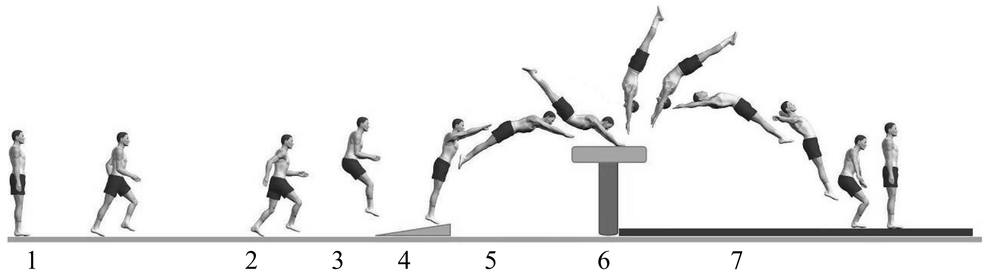

Figure 1. Vault seven phases (Atiković, 2012).

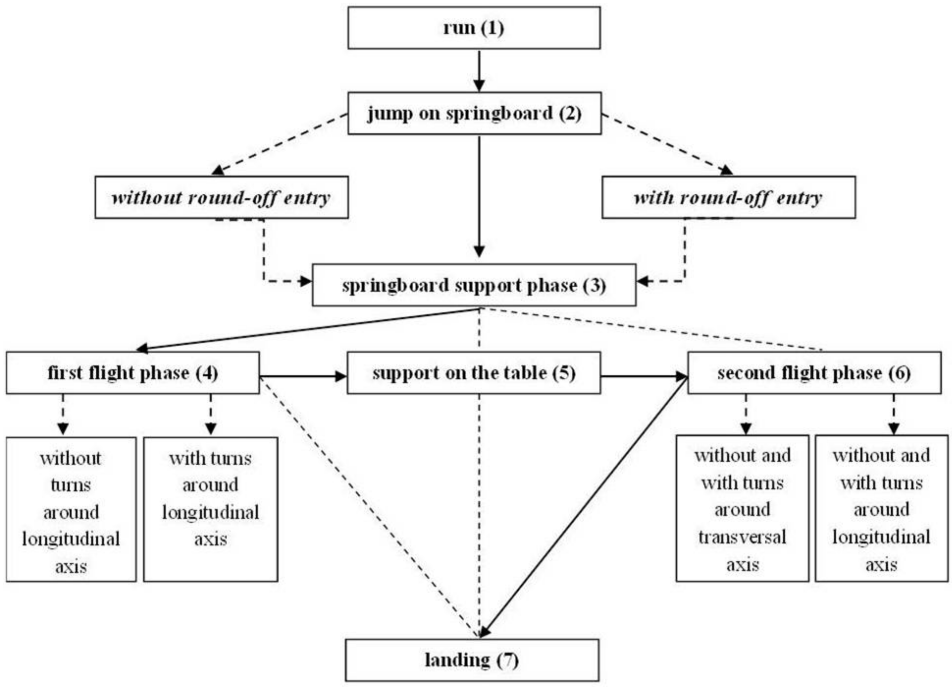

Figure 2. Schematic presentation of a possible jump to the vault (Atiković, 2012).

Isokinetic training allows maximal muscle loading throughout the full range of motion rather than at a specific angle as in an isotonic exercise, and the application of a specific isokinetic training program can efficiently restore imbalances in knee muscle strength (Gioftsidou et al., 2008). Isokinetic training allows for maximal strength improvements and is usually combined with other types of strength training. Selecting low strength speed ($60°\cdot s^{-1}$), medium fast speed ($180°\cdot s^{-1}$), or high endurance speed ($300°\cdot s^{-1}$), isokinetic testing speeds are essential for optimal strength evaluation (Baltzopoulos & Brodie, 1989).

There are limited intervention studies on artistic gymnasts. Previous findings suggested that a gymnastic intervention program improved lower limbs strength in pre-adolescent athletes (Douda et al., 1997; Pienaar & Van der Walt, 1988). Bassa et al. (2002) described the isometric and isokinetic knee torque in prepubescent male gymnasts six months after the beginning of the annual training period and concluded that long-term gymnastic training is associated with increased torque in knee extensor but not knee flexor muscles.

The handspring vault is a technical gymnastic skill that demands considerable force and power output and is of paramount importance for a gymnast's vaulting development. A study by Hall et al. (2016) examined the plyometric training effects, when added to habitual gymnastic training, on handspring vault performance variables in twenty youth female competitive gymnasts and found significant improvements for run-up-velocity, take-off velocity, a hurdle-to-board distance, board contact time, table contact time, and post-flight time.

Tabaković et al. (2016) research findings showed that isokinetic training of knee extensor and flexor muscles increases functional correlation between speed and strength, leading to improved performance of acrobatic elements in floor exercises.

Authors' Dallas et al. (2021) study investigated the effect of an isokinetic training program on muscle strength and gymnastic performance in preadolescent female gymnasts. However, the handspring vault requires both technical skill and power production to achieve success. The 10-week isokinetic training that was added to the traditional training improved the knee strength, which consequently improved aspects of the vault, but did not affect other technical aspects of the handspring performance.

To the best of our knowledge, there are no other studies that have examined the effects of isokinetic training on the knee stabilizer muscles strength and the performance of gymnastic vaults in college students. Therefore, the main purpose of this research was to examine the effects of a 12-week isokinetic training program on the knee extensor and flexor muscles strength, and whether it increases the efficiency of performing basic gymnastic vaults in students. It is hoped that this study will focus attention upon this important performance aspect of gymnastic vaults and stimulate interest in future scientific investigations in this area.

Our research hypothesized that an additional 12-week program of isokinetic training would increase the knee extensor and flexor muscles strength, facilitating better gymnastic vaults performance in students.

METHODS

This study included sixty students (n=60) of the Faculty of Sports and Physical Education at the University of Sarajevo, (mean age 19.7±1.5 years, weight 75.3±2.9 kg, height 179.8±6.7 cm). Using the random sample method, the subjects were divided into two groups, experimental (EG) (n=30) and control (CG) (n=30). All procedures were conducted in accordance with the Declaration of Helsinki, as well as according to the ethics committee standards of the Faculty of Sports and Physical Education at the University of Sarajevo. The study was conducted within one academic year semester (3 months). All subjects who had an injury to the lower extremities in the last six months were excluded from the procedure.

All subjects of the experimental (EG) and control group (CG) performed a regular practical lessons program in sports gymnastics. In addition to the regular gymnastics classes program, the experimental group subjects had additional isokinetic training of the knee stabilizer muscles on the Biodex 3 system dynamometer. The knee stabilizer muscles strength assessment was performed in the initial and final measurements in both groups, and in the final measurement, an assessment of gymnastic vaults performance was also conducted. The research participants were thoroughly acquainted with the research program before the start.

In this research, body height and weight were measured for each participant in the experimental group (EG) and control group (CG), in the initial and final measurements. Body height and weight were measured using an InBody BSM370 stadiometer (InBody Co.).

The strength test on knee joint extensor and flexor muscles was conducted using Biodex System 3 (Biodex Corporation, Shirley, New York, USA) isokinetic dynamometer. All knee joint extensor and flexor muscles strength measurements were performed from a sitting position with a 90° average angle of the body and upper leg. Bands for stabilization were positioned over the body, hips, and the distal upper leg part for the tested leg. During the whole isokinetic training procedure, examinees held their hands crossed on their chests. Also, during the examination, the examinees were given instructions to give their maximum effort for each exercise.

A standardized test routine improves the operator's control of several variables which influence tests: testing of the uninvolved side first, the axis of rotation alignment, warm-ups, subject stabilization, verbal commands, visual feedback, test position, system calibration, angular velocity selection, system stabilization, skill, education of the examiner, gravity compensation, rest intervals, test repetition, data collection (print - out) for future analysis, data analysis using statistical software (Biodex Medical Systems).

Most used isokinetic angular velocities are $60°\cdot s^{-1}$, $180°\cdot s^{-1}$, and $300°\cdot s^{-1}$; often referred to as slow, medium, and high speed. Selecting low strength ($60°\cdot s^{-1}$), medium ($180°\cdot s^{-1}$), and high endurance ($300°\cdot s^{-1}$) isokinetic testing speed is essential for optimal strength evaluation, given that in slow muscle action the vast majority of motor units are recruited, while faster testing velocities enrich the force-velocity spectrum of the acting muscles (Baltzopoulos & Brodie, 1989).

In this study, an isokinetic angular velocity of 60°·s–1 was used to determine the knee joint extensor and flexor muscles strength. That angular velocity was chosen because 12 weeks of additional training was realized at that angular velocity. Another reason that this angular velocity was chosen was because the student participants encountered gymnastic vaults for the first time, and it turned out that this angular velocity was the most optimal for them to be able to apply force in conditions similar to those encountered during the take-off phase from the springboard. In support of the chosen angular velocity is the studies of Tabaković et al. (2016) and Dallas et al. (2021), which found that knee strength at 60°·s–1 improved significantly in the EG after the isokinetic training program in contrast to the CG which indicated no significant improvement.

In this research, the following variables were used to assess the maximum muscle strength of dynamic knee stabilizers (Table 1).

Each of the listed variables for assessing the maximum muscle strength of dynamic knee stabilizers can be influenced. Peak torque (PT) - highest muscular force output at any moment during a repetition expressed in (Nm). Peak Torque indicates the muscle's maximum strength capability. Variables indicate results separately for extension and flexion of the left and right leg. Total work (TW) - the amount of work accomplished for the entire set. This represents the muscle's capability to maintain torque throughout the test bout. If the ROM is smaller on one side, the total work will be affected even if the peak torque is the same. Average power (AVG power) equals the amount of total work divided by the time to complete that total work. This value is used to provide a true measure of work rate intensity defined as total work divided by time. Power represents how quickly a muscle can produce force. It expresses the ability of the muscle to do the work for a specified period, and the intermuscular ratio (AGONIST TO ANTAGONIST RATIO) is expressed in percentages for both legs (Biodex Medical Systems).

As shown in Figures 3 and 4, to evaluate the success of performing elements of gymnastic vaults, the following were used:

- ST – squat through
- FHS – front handspring vault

Table 1
Variables for estimating maximum muscle strength of the dynamic knee stabilizers.

Maximum muscle strength of knee extensor	EXTLEF60 (Nm) – peak torque of the knee extensors of the left leg EXTRIG60 (Nm) – peak torque of the knee extensors of the right leg EXLFTW60 (J) – total work of the knee extensors of the left leg EXRGTW60 (J) – total work of the knee extensors of the right leg AVGEXLF60 (W) – average power of the knee extensors of the left leg AVGEXRG60 (W) – average power of the knee extensors of the right leg
Maximum muscle strength of knee flexors	FLXLEF60 (Nm) – peak torque of the knee flexors of the left leg FLXRIG60 (Nm) – peak torque of the knee flexors of the right leg FXLFTW60 (J) – total work of the knee flexors of the left leg FXRGTW60 (J) – total work of the knee flexors of the right leg AVGFLLF60 (W) – average power of the knee flexors of the left leg AVGFLRG60 (W) – average power of the knee flexors of the right leg
The ratio between knee flexor and extensor muscles	AGANLF60 – intermuscular ratio (Flexors/Extensors) of the left leg AGANRG60 – intermuscular ratio (Flexors/Extensors) of the right leg

Figure 3. ST – squat through (Atiković et al., 2009)

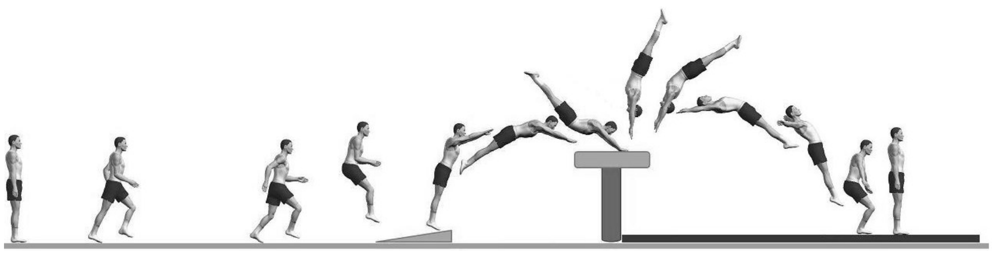

Figure 4. FHS – front handspring vault (Atiković, 2012).

The participants did not have prior knowledge of gymnastic vaults. Therefore, the initial performance assessment of gymnastic vaults (ST – squat through and FHS – front handspring), was not conducted. However, after the basic 12-week program of regular practical training, a final evaluation of the experimental and control groups was conducted by university lecturers (N=4) with more than 20 years of work experience in various sports clubs and at the Faculty of Physical Education and Sports. Evaluation of gymnastic vaults motor knowledge was conducted at the gym hall on a gymnastic apparatus for the vaulting of 135 cm height, with a maximal run-up of 25 m, using "Elan" springboard for take-off. Before the assessment, the examiners carefully read the description of the assignment and the criteria (Table 2). Each examiner evaluated the participants in silence and not making their evaluations public. Once the assessment was completed, the three evaluations (N=3) that were the closest to the mean values were taken, while the evaluations that had the largest deviations from the mean value were excluded from the final evaluation.

The subjects performed both gymnastic vaults (ST – squat through and FHS – front handspring) twice, and only the better performance was used in the analysis. After evaluation of better performances, the final grade for each examinee in each task was calculated as the arithmetic means of the grade assigned by each examiner. The final evaluation was made using a scale from 6 to 10 points, according to the criteria, where 10 points was the highest/best score. The same procedure was followed by seven teachers, experts in the field of gymnastics, to set the criteria for optimum performance of a "handspring" vault (Milosis et al., 2018).

Table 2
Criteria for Gymnastic vaults knowledge evaluation.

Measuring scale (points)	Description of standards - Gymnastics Vault
Points 10	The exercise (vault) is performed optimally in such a way that there are no mistakes in the initial position, body position, leg, and/or hand positions. There are no mistakes in the aesthetic part of the exercise, in the coordination of performance, technical performance, range of motion, speed, and pace, and finally, there are no mistakes in the final position.
Points 9	The exercise (vault) is performed optimally with minor errors found in certain technical requirements of the initial position, body position, and position of the legs and/or hands. Possible minor errors may be found in the aesthetic part of the exercise, range of motion, speed and pace, and final position. The total maximum number of minor faults is 1 to 2.
Points 8	The exercise (vault) is still well-performed with a small number of errors noticed in certain technical requirements of the initial position, body position, and position of the legs and/or hands. Possible errors may be found in the exercise's aesthetic part, performance coordination, range of motion, speed, pace, and final position. However, these errors do not impair the whole structure of the movement. The total maximum number of minor errors is 3 to 4.
Points 7	The performance of the exercise (vault) is flawed. There are errors in almost all the above-mentioned technical requirements. There is also a noticeable distortion in the structure of the movement.
Points 6	The exercise (vault) is poorly performed with a large number of errors. There are major deficiencies in all of the abovementioned technical requirements. The structure of the movement is significantly impaired.

All subjects of the experimental (EG) and control group (CG) performed a regular program of practical lessons in sports gymnastics. The regular practical lessons program in sports gymnastics, as shown in Table 3, consisted of three hours a week lasting 45 minutes each, a total of 135 minutes per week, for 12 weeks. The regular classes protocol included the following: warming up the body for 10 min, stretching the body for 25 min, and practical sports gymnastics exercise for 100 min. In the program performed by subjects from the control group, there was no additional stimulus, such as training on the dynamometer of the Biodex 3 system.

Table 3
A regular program of practical lessons in sports gymnastics (EG) and (CG).

Exercise	Regular sports gymnastics classes
3 classes x 45 min	Body warmup for 10 min
	Body stretching for 25 min
$\sum$ 135 min	Practical exercise of sports gymnastics (100 min)

The experimental group (EG) of examinees followed an isokinetic program of exercise (Table 4) three times a week x 40 min for 12 weeks. All subjects had knee range of motion (ROM) by 90 degrees. Knee testing angular velocity was set at $60°\cdot s^{-1}$ for concentric and eccentric muscle action. Participants were encouraged to exert maximum effort. Standard instructions were given to each subject. The testing protocol included the following: warm-up and overall body stretching – 20 min; positioning the examinee in optimal stabilization; alignment of joints and dynamometric axis of rotation; positioning the resistance pad; verbal introduction into the isokinetic concept of exercises; gravitation correction; warm-up (3 submaximal, 1 maximal repetition); maximum test speed of $60°\cdot s^{-1}$ (5 repetitions); rest (30 seconds); contralateral extremity testing, and recording test details to ensure test repeatability.

Table 4
Resistance training program (EG).

Exercise	Sets/Repetitions/Rest	Speed
	Warming up on bicycle ergometer for 10 min (75 RPM, 50 WATT)	
	Static stretching muscles of lower extremities (10 min)	
3 sets	4 - 6 repetitions	with the left leg on the angular speed of $60°\cdot s^{-1}$
	pauses of 30s between the series	
3 sets	4 - 6 repetitions	with the right leg on the angular speed of $60°\cdot s^{-1}$
	pauses of 30s between the series	
	Pause between exercises of 3 min	

The Statistical Package for the Social Sciences (SPSS), version 21.0 (SPSS Inc., Chicago, Illinois) was used for data processing. Descriptive statistics (mean value and standard deviation) were calculated for all variables and each group. ANCOVA was used to determine the effects of the experimental program. As a preliminary analysis (assumption) for ANCOVA, the Levene's test was used to evaluate the equality of variances between the compared groups. The Mann-Whitney U test was used to determine the differences between the experimental and control groups in the vault performance scores. The Kolmogorov-Smirnov test was used to check the normality of the distribution.

RESULTS

The results of the arithmetic means and standard deviation for variables of average age, body height, and body weight for experimental (EG) and control (CG) groups in initial measurement are presented in Table 5. Going through the results, we can conclude that there are no differences in arithmetic means in the results of the applied variables. Average values of average age for the experimental and control group were calculated, and they were within the following range: EG: 19.9±1.6; CG: 19.8±1.4; the values for body height EG: 179.63± 6.19; CG: 180.81± 7.40, and values for body weight were the following: EG: 75.11± 3.35; CG: 75.90± 3.13. *p*-values are based on comparisons of the experimental group and control group of average age (*p* =.42), body height (*p*=.51), and body weight (*p* =.35). From the statistical point of view, there were no differences between the control and the experimental group.

Table 5
Comparison of three variables after the initial measurements (M ±SD) and (p).

Variable	(EG) *M ± SD* (*n*=30)	(CG) *M ± SD* (*n*=30)	*p*
	Initial measurement		
Average age (years)	19.9±1.6	19.8±1.4	.42
Height (cm)	179.63± 6.19	180.81± 7.40	.51
Weight (kg)	75.11± 3.35	75.90± 3.13	.35

Data are presented as the *M* ± *SD*. *p*-Values are based on comparisons of the experimental group (EG) and control group (CG) using ANOVA

The first analysis was conducted on the experimental (EG) and control groups (CG) before the program's implementation. The results presented in Table 6 show that from the statistical point of view, examinees are not substantially different in all strength variables for knee extensor and flexor muscles. Preliminary testing tested the assumption of variance homogeneity; no perceived contingency was noted in the applied variables. The statistical significance of Levene's test in all variables is $p>.05$, indicating that the observed variances for the two groups of respondents are similar in these variables, which means that there are no significant differences between the variables. The null hypothesis is accepted, and we conclude that the condition of homogeneity is met. Therefore, the differences in the final measurement between the groups can be attributed to the effects arising from the experimental program. ANCOVA showed that a significant difference was found for all variables in the maximum knee extensor and maximum knee flexor muscles strength, between unspecific and specific training program on Biodex 3 ($p<.05$).

The calculated effect size (Partial eta-squared) for all variables assessing the knee extensor and flexor muscles strength ranges from (η_p^2 = .09) to (η_p^2 = .18), which indicates a medium and high effect size value. In the variables for assessing the knee extensor and flexor muscles ratio, Leven's test obtained statistical significance (p<.05), which means that the null hypothesis is rejected, and there are statistically significant differences in the initial measurements between the groups. By analyzing the arithmetic means in the initial and final measurements, it can be concluded that the arithmetic means in the final measurement are almost equal, which means that the differences in the ratios between the knee extensor and flexor muscles have decreased.

Table 6
ANCOVA of dynamic knee stabilizer muscles between experimental and control groups in the initial and final measurements (speed 60°·s^{-1}).

Variable	Group	Initial measurement $M \pm SD$	Final measurement $M \pm SD$	Levene's statistic p	ANCOVA df	F	p	η_p^2
Maximum muscle strength of knee extensors								
EXTLEF60 (Nm)	EG CG	210.27±37.93 217.04±37.40	264.57±44.96 229.04±40.14	.76	1.00	10.07	.02*	.15
EXTRIG60 (Nm)	EG CG	204.93±32.40 218.39±35.16	257.35±44.38 220.32±37.56	.74	1.00	11.05	.02*	.16
EXLFTW60 (J)	EG CG	856.00±173.54 946.47±187.28	1123.98±217.19 964.47±149.11	.06	1.00	10.89	.00*	.16
EXRGTW60 (J)	EG CG	859.79±123.32 905.92±117.88	1118.53±223.23 932.80±169.15	.27	1.00	12.26	.00*	.18
AVGEXLF60 (W)	EG CG	132.92±21.59 136.58±16.96	172.42±39.95 145.62±27.82	.09	1.00	9.70	.00*	.15
AVGEXRG60 (W)	EG CG	125.21±12.55 127.30±10.31	167.05±39.91 141.86±28.92	.21	1.00	7.37	.01*	.12
Maximum muscle strength of knee flexors								
FLXLEF60 (Nm)	EG CG	119.60±14.21 124.58±11.91	151.20±26.73 132.69±25.90	.83	1.00	7.01	.01*	.11
FLXRIG60 (Nm)	EG CG	130.25±20.46 135.70±24.71	149.60±27.99 132.03±26.40	.90	1.00	5.68	.02*	.09
FXLFTW60 (J)	EG CG	501.15±54.58 489.26±66.54	789.84±159.86 673.58±142.32	.33	1.00	8.50	.01*	.13
FXRGTW60 (J)	EG CG	547.40±72.50 525.18±71.79	799.98±152.98 663.90±157.03	.82	1.00	11.95	.00*	.17
AVGFLLF60 (W)	EG CG	90.14±6.30 92.02±7.24	113.37±22.78 96.46±22.03	.93	1.00	9.20	.00*	.14
AVGFLRG60 (W)	EG CG	93.12±18.18 90.83±13.86	115.73±24.66 94.83±22.34	.67	1.00	11.48	.00*	.17
The ratio between knee flexors and extensors (F/E ratio)								
AGANLF60 (%)	EG CG	54.31±3.44 56.59±5.50	58.88±3.66 58.26±7.52	.00	1.00	.15	.70	.00
AGANRG60 (%)	EG CG	58.67±5.82 62.12±8.71	60.74±3.93 60.13±7.49	.00	1.00	.00	.98	.00

Data are presented as the $M \pm SD$. Levene's test p-level of statistical significance. df-Degree of freedom. F-F ratio. p-Values are based on comparisons of the experimental group (EG) and control group (CG) using ANCOVA. η_p^2-Partial-eta squared. *. The mean difference is significant at the .05 level

The Mann-Whitney U test, represented in Table 7, was used to evaluate the differences in performance ratings of gymnastics vaults between the experimental and control groups. The test showed statistically significant differences ($p<.05$) between the experimental and control groups in both vaults. Based on the formula for calculating the size of the effects, statistically significant values were obtained for both vaults ($r=.59$), which means that there are large differences in the scores between the groups.

Table 7
Mann-Whitney U test for the gymnastics vaults performance evaluation.

Variable	Group	*M rank*	*U*	*z*	*p*	*r*
ST – squat through	EG (n=30)	40.10	162.00	-4.56	.00*	.59
	CG (n=30)	20.90				
FHS – front handspring	EG (n=30)	40.32	155.50	-4.60	.00*	.59
	CG (n=30)	20.68				

Data are presented as the *M rank*-Mean rank. *U*-Mann-Whitney test value. *z*-z-score. *p*-Values are based on comparisons of the experimental group (EG) and control group (CG). *r*-Pearson's correlation. *. The mean difference is significant at the .05 level

DISCUSSION

This study examined the effects of a 12-week isokinetic training program on the knee stabilizer muscles strength and the performance of gymnastic vaults in college students. The aim of this study was to examine whether the additional protocol of 12-week isokinetic training results in increased biomechanical values of certain parameters, but also to determine whether isokinetic training or resistance training increases the functional correlation between speed and strength, leading to improved performance of gymnastic vaults. The main finding is that the EG achieved better results than the CG in the strength of the knee stabilizers and the efficiency of performing gymnastic vaults after the program in the final measurement. Another finding was that knee stabilizer muscles strength at an angular velocity of $60°\cdot s^{-1}$ was significantly improved in EG after a 12-week program intervention, in contrast to CG, where there was no significant improvement. This finding is confirmed by the results of the research by Tabaković et al., (2016) and Dallas et al. (2021).

The control group had a different work protocol during 12 weeks than the experimental one, because between the two measurements for the control group, only a regular practical lessons program in sports gymnastics was conducted, without an additional exercise program. In the program, to which the examinees from the control group were subjected, there were no additional stimuli, such as training on the Biodex System 3 dynamometer; therefore, the whole process was focused on the regular practical classes at the faculty. Therefore, structural changes in the maximum dynamic knee stabilizer muscles strength occurred with lower intensity for the control group.

The experimental group indicated obvious structural changes, which could be dominantly registered through variables for the assessment of the maximum dynamic knee stabilizer muscles strength (the maximum moment of force, overall work, and average strength).

In the initial measurement, before the implementation of the program, the groups indicated practically no differences, which is an excellent indicator of a balanced position for the possible application of a specific additional training program of the dynamic knee stabilizer muscles, with two applied transformation procedures. However, in the second measurement (at the end of the program), the groups indicated significant differences in the assessment of the maximum dynamic knee stabilizer muscles strength, as well as in the assessments of vault performance, and the obtained changes are in favor of the experimental group compared to the control group.

In variables assessing the maximum dynamic knee stabilizer muscles strength and variables assessing the gymnastic vaults' performance, we obtained statistically significant differences in almost all applied variables.

It was determined, when it comes to the gymnastics vault elements, that the changes obtained for both gymnastic vaults, which required the change of the maximum dynamic knee stabilizers strength, were statistically more significant.

The results of our research partially agree with the data obtained in the research studies mentioned below. Explosive strength, which is defined as the ability to activate the maximum number of muscle units in a unit of time, has significant correlations with success in performing artistic gymnastics elements and elements of other sports in the majority of research (Lešnik et al., 2015; Mujanović et al., 2014).

One of the factors affecting the performance results is the take-off speed on the springboard (Bradshaw et al., 2010). The fact that no significant improvement was shown in knee strength at 300°/sec is one of the reasons why both groups failed to affect the take-off phase from springboard due to the fast duration of this phase. It explains why we took a smaller angular speed of 60°/sec in our research.

The results of our study are consistent with data confirming the effectiveness of isokinetic training to improve muscle strength in trained athletes (Zebrowska et al., 2005), and they verify the findings of Pienaar and Van der Walt (1988) and Douda et al. (1997) who stated that young gymnasts improved vertical jumping performance and explosive strength of lower limbs after a specialized training program. These facts lead to the conclusion that for a successful performance of applied vaults, more significant engagement of musculature is necessary on the principle of transitory activation of the maximum muscle units' number in the unit of time (explosive strength of lower extremities).

The correct performance of the handspring vault requires the correct body position during various phases of the vault and sufficient explosive power and speed in the lower limb musculature in order to perform body rotation while maintaining body control (Marina & Jemni, 2014).

The results of Rochcongar's study (2004) suggest that both training modalities (isokinetic and traditional training) are equally effective in artistic gymnastics in relation to the lower limb strength. The author also suggests that isokinetic exercises have several advantages over other exercise modalities, such as (i) that a muscle group may be exercised to its maximum potential throughout a joint's entire range of motion; (ii) it provides a safer alternative to other exercise modalities.

Preparing additional training for the dynamic knee stabilizer muscles (and probably on many other types of muscles) by using training protocols on isokinetic equipment would prove to be the best solution, first of all, because of the optimum training load possibility for a performer, and continuous resistance which is allowed by this equipment (Cools et al., 2007; Teng et al., 2008).

Certainly, precise defining of sorts and types of protocol, number of repetitions depending on transformation stages and the objectives of the work, overall volume, and specific content, should all be developed in accordance with the characteristics of muscle groups, which is a topic for future research. It is completely certain that the applied training in this study eventually proved to be an important method for improving dynamic knee stabilizer muscles strength, as well as a significant influence on the improvement of effectiveness in performing elements of gymnastic vaults.

In a study conducted by Calmels et al. (1995), the effects of intensive training on concentric and eccentric isokinetic flexor and extensor muscles strength of 9 young national competitors in gymnastics were tested using an isokinetic dynamometer at angular speeds of $60°\cdot s^{-1}$ and $120°\cdot s^{-1}$. Authors present in their results that eccentric strength is greater than concentric strength, there is no significant difference between the dominant and non-dominant limb, and a significant increase of the flexor/extensor peak torque ratio was observed with increasing speed, due to the concentric ratios. The same increase in flexor/extensor peak torque ratio values was observed by Siatras et al. (2004) in young male gymnasts, between angular velocities of 60-120°/s ($p<0.01$) as well as 60-180°/s ($p<0.01$). These results provide information about the relationship between angular velocity and eccentric muscle strength, already reported in previous studies, and, in particular, the fact that the knee flexor and extensor muscles behave differently during eccentric and concentric work as the angular velocity increases.

The results of our study are consistent with the data of the study of Tabaković et al. (2016), which concluded that the maximum dynamic knee stabilizer muscles strength significantly affects the success of floor exercises in artistic gymnastics. This study examined whether additional training protocol of isokinetic training results in increased biomechanical values of certain parameters and whether it increases functional correlation between speed and strength, leading to improved performance of acrobatic elements in floor exercises. The experimental group indicated obvious structural changes that can be dominantly registered through variables assessing the maximum dynamic knee stabilizers strength. In variables assessing the performance of floor exercise elements in artistic gymnastics, authors obtained statistically significant differences in elements requiring maximum dynamic knee stabilizers strength changes: dive roll, back handspring, and forward and backward somersault. The above facts lead to a conclusion that for a successful performance of applied acrobatic elements on the floor for this type of performance, more significant engagement of musculature is necessary on the principle of transitory activation of the maximum number of muscle units in the unit of time (explosive strength of lower extremities).

A study conducted by Dallas et al. (2021) investigated the effect of an isokinetic training program on muscle strength and gymnastic performance in preadolescent female gymnasts. However, the handspring vault requires both technical skill and power production to achieve success. The 10-week isokinetic training that was added to the traditional training improved the knee strength, which consequently improved aspects of the vault, but did not affect other technical aspects of the handspring performance. However, further research should aim to examine whether the incorporation of additional specific exercises, such as sprinting or jumping movements, may have a positive influence on the performance score. The results of the study confirm that optimal performance is the result of a complex interaction of several factors.

Control, management, and distribution of training load are important factors not just in terms of intensifying the teaching process, but also in bringing the process of additional training closer to the authentic problems of students. This happens mostly due to the fact that the influence of adequate kinesiology operators in the appropriate time and space (which implies the implementation of certain control, management, and load distribution) leads to positive changes in motor abilities and motor skills appear. In other words, adaptive changes partially occur in muscles. This also has a positive influence on creating favorable adaptive structures and a better overall functional state of student bodies. It is clear that such students adapt better to the load during the learning process, but also reduce the risk of injuries due to weak muscle strength. Therefore, the overall effects of solving various motor tasks would be larger.

In our research, the strength of the knee extensor and flexor muscles came to the fore in both applied vaults, especially in the front handspring. Greater activation of knee extensor and flexor muscles strength was required in certain phases of the vault, namely: running, jump on springboard, springboard support phase, and first flight phase. Our results are supported by Marinšek (2010), who stated that in artistic gymnastics all phases of vaults exercises such as running, jump on springboard, springboard support phase, first flight phase, and landing, depend on the physical preparation and motor control of the gymnasts.

This research has some limitations in theoretical and practical utility. These limitations are reflected in the fact that the results of our research can mainly be applied to the population of sports faculty students, so they cannot be generalized and may not be applicable to high-level gymnasts. Also, one of the limitations is that in addition to the strength of the extensor and flexor muscles of the knee, other muscles of the body that were not covered by this research are also important for the success in performing gymnastic vaults.

CONCLUSIONS

This study investigated the effects of an isokinetic training program on muscle strength and performance of gymnastic vaults. The 12-week isokinetic training program improved knee strength, which consequently improved aspects of the vaults. In the initial measurement of our research, before conducting the training program, the two groups, experimental and control, showed no differences. However, in the second measurement (at the end of the program) the groups showed significant differences in the assessment of the maximum dynamic knee stabilizer muscles strength, as well as in the assessment of performance of gymnastic vaults. The changes obtained after the experimental training in the isokinetic dynamometer and regular faculty classes, lasting 12 weeks, are in favor of the experimental group compared to the control group, both in variables for assessing the knee extensor and flexor muscles strength, as well as in the variables for assessing the success in performing gymnastic vaults.

The value of this study is reflected in the fact that the applied isokinetic training can be used as training to increase the knee stabilizer muscles strength, which leads to easier learning and better performance of gymnastic vaults in a population that has no previous experience in sports gymnastics.

Future research should be conducted on a population of high-level gymnasts and should aim to examine whether the inclusion of additional specific exercises, in addition to knee stabilizer strength training, such as lunge training, jumping training, and training involving arm and shoulder girdle strength can, have a positive effect on performing gymnastic vaults.

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