

# THE INFLUENCE OF STRENGTH ON THE GYMNASTS' SUCCESS IN PERFORMING VAULT

Miloš Paunović, Saša Veličković, Tomislav Okičić, Stefan Jović and Dušan Đorđević

Faculty of Sport and Physical education, University of Niš, Serbia

*Original article*

*DOI:10.52165/sj.14.2.173-183*

## **Abstract**

*The aim of the study was to determine the influence of absolute and relative strength of the muscles of the legs, upper arms and shoulder girdle on the success of performing vault with gymnasts aged 13 to 16 who have been training gymnastics from five to 12 years. The Japanese digital dynamometer IMADAZ2H-1100 with WinWedge 3.4 software was used to estimate the absolute strength of the leg, upper arm and shoulder girdle muscles. The values shown on the digital meter represented the absolute value of the maximum force, and when the absolute value of the force was divided by the weight of the participant, the value of the relative force was obtained. Regression analysis was used to determine the influence of absolute and relative strength of leg muscles, upper arm and shoulder girdle on the success of performing vault. The results showed that although there is an influence of the above muscles, it is not statistically significant. Specifically, for a successful performance on the vault, the muscles of the shoulder girdle have the greatest influence (without statistical significance). The reason for the results obtained in this way lies in the fact that the phase of flight and landing depends on the support phase and the repulsion from the vault. As there are few research studies on the subject of this paper, regardless of the obtained results, this research represents a good foundation and basis for some future research of absolute and relative strength in artistic gymnastics.*

**Keywords:** *vault, gymnasts, absolute strength, relative strength.*

## **INTRODUCTION**

In addition to swimming and athletics, artistic gymnastics is one of the basic sports and represents a type of sports competition that reaches the highest level of artistic achievement (Petkovic, Veličković, Petkovic, Hadzi – Ilic, i Mekic, 2013). Under the generic name "gymnastics", FIG (Federation International Gymnastics) with regulations regulate a large part of activities based on training, education and activities that will emphasize the physical and mental characteristics of the athlete regardless of race, religion, age, his or her social status.

Due to the existence of several types of gymnastics, gymnastics today must be used with a prefix in order for the term to be clearly defined (Petkovic, 2011). "Under artistic gymnastics, the widest audience experiences sports, conceptually defined as a competitive discipline, with polystructural content (exercises are performed in all three planes of movement and around all three axes of rotation) of acyclic type and strictly defined rules as a convention in practice". These exercises are usually performed in anaerobic conditions, with the aim of showing the form of movement and making a visual impression (Petkovic, Veličković, Petkovic, Hadzi – Ilic, i Mekic, 2013, pg. 12).

The vault, present in both men and women gymnastics, is one of the more attractive apparatuses. Gymnasts start vaulting from a calm position, with their legs joined at a maximum distance of 25 meters from the apparatus, where the first step or jump is counted as the beginning of performing a vault. It consists of two phases: the first phase is the flight from the springboard to the support on the vault, and the second phase includes the flight phase, from pushing from the vault to landing on both feet (FIG, 2017). The gymnast is obliged to perform one vault. But in qualifications for finals and in the finals on the vault, two vaults are performed from two different groups and with a different second phase of the flight. Each vault can have one or more rotations around both axes of the body, or it can be performed without rotation (Petkovic, Velickovic, Petkovic, Hadzi – Ilic, i Mekic, 2013).

There are a number of definitions of motor abilities. Findak (1999) and Prskalo (2004) similarly defined motor abilities as latent motor structures responsible for an infinite number of manifest reactions, which can be measured and described. Milanovic (2009) defined motor abilities as the ability of the body to realise all types of movements. Malacko and Popovic (2001, pg. 26) state that "motor abilities are latent, they cannot be measured directly but indirectly, which means that only motor reactions, i.e., manifestations of different units of measurement, can be measured directly". Milanovic (2009) states that according to Meinel (1977), it is a complex structure of quantitative (strength, speed, endurance, flexibility) and qualitative (coordination, agility, balance and precision) motor abilities (Badric, Sporis, Trklja, and Petrovic, 2012).

Most experts (Kurelic et al., 1975; Kukulj, Jovanovic, and Rupert, 1992; Nicin and Kalajdzic 1996) agree that in the latent space of basic motor abilities, the following features stand out:

- strength,
- coordination,

- endurance,
- speed,
- flexibility,
- balance, and
- precision.

Many authors have tried to define strength in the most adequate way by using different starting points. Thus, Opavski (1971, p. 169) identifies strength with force and says that "force is the ability to transform muscular tension in the composition of motor units into a kinetic or potential form of mechanical energy". In anthropometrics, the term strength is defined as a human trait, i.e., its ability to overcome some external resistance or to oppose it with the help of muscular strains (Nicin, 2000). Strength represents the work of muscles in a unit of time against the force of gravity in overcoming the resistance offered by muscle contraction (Ugarkovic, 2004). Stone (1993) and Sif (2001) defined muscular strength as the ability to exert force on an external object or resistance. The most common criterion for classifying motor ability strength is the ratio of the magnitude of the force exerted to the mass of the body. It can be isolated on this basis of:

- absolute strength (maximum muscle strength that a person can develop with his/her overall muscle mass), and
- relative strength (amount of strength that a person can develop per kilogram of his/her weight) (Stojiljkovic, 2003).

The aim of the study was to determine the influence of absolute and relative strength of the muscles of the legs, upper arms and shoulder girdle on the success of performing vault in gymnasts aged 13 to 16 years.

In previous research studies related to vault, the authors have examined a variety of variables. Scharer, Lehmann, Naundorf, Taube & Hubner (2019) examined the relationships between run-up speed; the degree of difficulty (D-score); height and length of flight on the vault in artistic gymnastics for handspring; Tsukahara and Yurchenko-style vaults, and compared the

performances of male and female elite and junior athletes during the 2016 European Championships. The results showed that for females, the run-up velocity correlated significantly with the difficulty (D) score and the height of flight for all vaulting styles ( $r \leq 0.80$ ). In males, the run-up velocity correlated significantly with the D-score, height and length of flight of Tsukahara ( $r \leq 0.69$ ) and Yurchenko vaults only ( $r \leq 0.65$ ). Males reached 8–9% higher run-up velocity performing handspring and Tsukahara vaults than females, but similar run-up velocity performing Yurchenko vaults. Both male and female elite gymnasts achieved higher run-up speeds than junior gymnasts. The authors concluded that the knowledge of the required run-up velocity for each vault helps coaches to estimate each athlete's potential and/or to focus the training on developing the required physical qualities. A similar group of authors (Scharer, Haller, Taube & Hubner 2019) examined "Physical determinants of vault performance and their age-related differences across male junior and elite top-level gymnasts" with the aim to: 1) investigate interrelations between difficulty value (D-score) and run-up kinematics of handspring/Tsukahara and Yurchenko vaults as well as lower body power (25m-sprint, explosive and reactive strength) and 2) to explore age-related differences of these parameters across junior and elite gymnasts performing handspring/Tsukahara vaults. On a sample of 47 top-level male elite and junior gymnasts aged 14.3 to 28.3, results showed that D-scores for handspring/Tsukahara ( $n = 33$ ) were strongly correlated with the run-up speed. There were no significant relationships with the D-score for Yurchenko ( $n = 14$ ). Looking at the age-related differences for handspring/Tsukahara, D-scores increased significantly from the junior to the elite level (+11.6%;  $p < 0.01$ ). The comparison between consecutive age groups revealed that the U19 group had higher run-up speeds, step lengths, body weights and

heights than the U17 group, while the U21 group achieved significantly higher speeds (run-up, 25m-sprint) and explosive strength than the U19 group. They concluded that 1) the optimization of important physical determinants may increase the potential to perform more difficult handspring/Tsukahara vaults, and 2) first growth and maturation and later improvements of lower body power led to higher run-up speeds for handspring/Tsukahara in the subsequent age-group. Atiković, Kazazović, Kamanješavić and Nožinović-Mujanović (2019) examined the correlation of biomechanical parameters and the vault start value in men's artistic gymnastics. The aim of their research was to determine the correlation between the vault start value and the run-up velocity, the first flight phase, the table support, and the second flight phase. In the correlation matrix, the criteria variables from the Code of Points FIG MAG (2017-2020) effected a statistically significant positive correlation with two variables: run-up velocity on springboard and the second flight phase, but a negative correlation with two other variables, i.e., the first flight phase and vault support. The authors concluded that there were no differences in the values in relation to the two cycle Code of Points. Hwang, Kim, Choi and Choi (2020) dealt with "Dynamic modelling for the second flight phase of the Yurchenko layout vault based on msc. Adams". They used a 3D angle-driven computer simulation model of a gymnast who performs the Yurchenko layout vault using ADAMS software. Their results showed that increasing the initial horizontal velocity resulted in an increased horizontal flight distance, but had no connection with the duration of the flight and the angle of twists. The overall angle of twists is concerned with initial vertical velocity and angular velocities about the transversal and longitudinal axes. Also, increasing the initial vertical velocity and angular velocity about the transverse axis leads to an increase in the touchdown angle between

the ground's horizontal axis and the gymnast's longitudinal axis.

In previous studies related to the strength in artistic gymnastics, authors have examined a variety of variables on a sample of respondents of different ages. The aim of the research of Kochanowicz et. al (2018) was to demonstrate the differences between non-athletes and gymnasts in the development of peak torque (PKTQ) in the pre- and post-pubertal age. They also examined the flexion/extension ratios at the elbow and the glenohumeral joints, as well as the relevance of the above activities for the co-activation of selected muscles. On a sample of 20 gymnasts and 20 non-athletes aged 8-9 years, in addition to 12 gymnasts and 16 non-athletes aged 18-25 years, the results showed that in the group of older gymnasts the PKTQ ratio of the glenohumeral flexors to extensors was the lowest (0.72) and was significantly different from the other groups. This result was consistent with the 30% higher PKTQ values ( $P < 0.01$ ) of the glenohumeral extensors and a 41% reduction in their EMG in flexion in comparison to non-athletes. Scharer et. al (2021) examined "Maximum strength benchmarks for difficult static elements on rings in male elite gymnastics". Subjects performed a concentric (1RM isoinertial) and eccentric (isokinetic: 0.1 m/s) conditioning strength test for the swallow/support scale (supine position) and inverted cross (seated position) on a computer-controlled device and a maximum strength test maintaining these elements for 5s on the rings with counterweight or additional weight. Results showed high correlation coefficients between the conditioning maximum strength for the swallow/support scale ( $r$ : 0.65 to 0.92;  $p < 0.05$ ) and inverted cross ( $r$ : 0.62 to 0.69;  $p > 0.05$ ) and maximum strength for the elements on the rings. Strength benchmarks varied between 56.66% (inverted cross concentric) and 94.10% (swallow eccentric) of body weight. They concluded that differences in biomechanical characteristics and technical

requirements of strength elements on rings may (inter alia) explain the differences between correlations. Dallas, Kirialanis, Dallas and Mellos (2017) dealt with effects of training maximal isometric strength on young gymnasts. Subjects (57 gymnasts and 74 non-gymnasts) were tested for isometric strength during force flexion and extension of the upper and lower limbs during a 5-second maximal voluntary isometric strength test for the right and the left side respectively. The results showed significant differences between gymnasts and non-gymnasts ( $p < .05$ ). Further, significant interaction revealed: a) for the right side with respect to the force flexion at the elbow and shoulder joints; b) for the left side with respect to the force flexion for the elbow, shoulder and hip joint, c) with respect to the force extension of the right side for the elbow, shoulder, hip and knee joints, d) for the extension of the left side for elbow, shoulder, and hip joints. In conclusion they indicated that such results should be considered by trainers seeking to improve the strength and overall training level of their athletes. Čeklić and Šarabon (2021) conducted a research study aiming to determine the differences in hip, knee, and ankle strength between female gymnasts and non-gymnasts, and secondly, to determine the effect of strength training interventions. Over the period of 8 weeks, the participants underwent 5 weeks of regular training and 3 weeks of targeted strength training intervention. After eight weeks, they were retested. It was found that there were significant differences between the two groups in the most observed hip strength parameters, but not in the knee and ankle strength. The intervention did not significantly affect any parameters of ILAs. Gymnasts and non-gymnasts differ in hip strength parameters. In conclusion, the authors stated that a longer intervention program might decrease the ILA parameters. Qomarrullah, Kristiyanto, Sugiharto and Hidayatullah (2018) examined the dominant factors of physical ability determining the achievement of

artistic gymnastic techniques on the vault. The aim of the study was to analyze the relationship between the physical ability factor of running speed, the strength of leg muscle, arm muscle, abdominal muscle, and balance in the vault technique. The results showed that the speed and the running factor had no significant influence; while the leg muscle strength, the arm muscle strength, and the abdominal muscle strength had a significant effect. The most dominant factor of physical ability in the vault technique is the leg muscle strength, while the influence of the running speed is the lowest.

## METHODS

The sample of respondents included 29 gymnasts (Table 1) from eight countries participating in the international tournament "Laza Krstic and Marica Dzelatovic" in Novi Sad, aged 13 to 16, who have practiced gymnastics from five to 12 years. The research was approved by the Ethics Committee of the Faculty of Sports and Physical Education, University of Nis, and was conducted in accordance with the Declaration of Helsinki (World Medical Association 2013).

The Japanese digital dynamometer IMADAZ2H-1100 with WinWedge 3.4 software was used to estimate the absolute strength of the leg, upper arm and shoulder girdle muscles. The values displayed on the digital meter represented the absolute value of the maximum force. When the absolute value of the force was divided by the weight of the participants, the value of the relative force was obtained. A scale (Gorenje) was used to estimate body weight and the results were recorded in kilograms (kg).

Table 1

*Sample of respondents.*

	Age	Training internship	Body weight
MIN	13	5	31
MAX	16	12	64
Mean	14.62	8.14	47.25

The measurement of the absolute force of the leg, upper arm and shoulder girdle muscles was performed immediately before the competition, so that it did not affect the outcome of the competition. To estimate the maximum force, the following features were measured: the maximum force of the leg extensors, the maximum force of the flexor muscles of the upper arm and the maximum force of the shoulder girdle muscles. The results (final score on vault) from the international tournament "Laza Krstic and Marica Dzelatovic" were used as an indicator of the success in performing vault.

To measure the maximum force of the leg extensors, the subject holds a dynamometer behind and below the back, with the knees in slight flexion and the feet spaced hip-width apart (Figure 1). The chain connecting the stand to the digital force meter is fully tightened. The subject pulls the dynamometer from the starting position with evenly extended arms with the strength of the extensor muscles of the lower extremities, during which he performs the movement of the extension in the knee joint. The result is measured in Newtons (N).



Figure 1. Leg extensors measurement.

To measure the maximum force of the upper arm muscles, the subject holds a dynamometer in front of him with a flexion in the elbow joint of 90 degrees (Figure 2). The feet are hip-width apart and the chain connecting the stand to the digital force meter is fully tightened. The subject pulls

the dynamometer from the initial position evenly with both hands with the strength of the flexor muscles of the upper arm, during which he performs the movement of flexion in the elbow joint. The result is measured in Newtons (N).

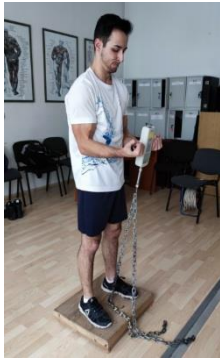


Figure 2. Upper arm muscles measurement.

To measure the maximum force of the shoulder muscles, the subject holds a dynamometer in front of him, arms outstretched with an angle of 90 degrees between the arms and the torso (Figure 3). The feet are hip-width apart and the chain connecting the stand to the digital force meter is fully tightened. The subject pulls the dynamometer from the initial position evenly with both hands with the strength of the shoulder girdle muscles, during which he performs the ante-flexion movement in the shoulder joint. The result is measured in Newtons (N). The description of the test was taken from Dopsaj, 2010.



Figure 3. Shoulder muscles measurement.

The sample of variables consisted of:

- final score on vault (DVAL),
- absolute leg muscle strength (ASLE),

- relative leg muscle strength (RSLE),
- absolute strength of the upper arm muscles (ASBI),
- relative strength of the upper arm muscles (RSBI),
- absolute strength of the shoulder girdle muscles (ASSH),
- relative strength of the shoulder girdle muscles (RSSH).

Statistical procedures corresponding to the problem under investigation were used for data processing. First, for each variable, descriptive parameters were calculated as follows:

- minimum value (MIN),
- maximum value (MAX),
- range (RAN),
- arithmetic mean (ARM),
- standard deviation (STD),
- skewness (SKE),
- kurtosis (KUR),
- Kolmogorov smirnov Z test (p).

Regression analysis was used to determine the influence of absolute and relative strength of the leg, upper arm and shoulder girdle muscles on success in performing vault. For this purpose, the following were calculated: standardized values of the regression coefficient – Beta, standardized tests of the significance of the regression coefficient – t, the level of significance of the standardized regression coefficient – p, coefficient of determination –  $R^2$ , adjusted coefficient of determination –  $R^2$  adjust, standard error estimate – Std. Err. Est., significance test of multiple regression analysis – F, significance level of multiple correlation – p. The statistical program "SPSS v20" was used for statistical data processing.

## RESULTS

Based on the obtained measurement results, adequate statistical procedures were applied.

Table 2 shows the basic statistical parameters of descriptive statistics and

Tables 3 and 4 show the regression analysis of absolute and relative strength, both sets of applied variables and for each variable separately.

Examining the results of descriptive statistics, it can be concluded that the results are normally distributed, as indicated by the values of skewness and kurtosis. The normality of the distribution of results is also confirmed by the values of Kolmogor's Smirnov Z test, which are higher than 0.05 for all applied variables.

The results of the regression analysis for absolute strength indicate that although there is an influence, it is not statistically significant, either for each variable separately (ASLE .290, ASBI .895, ASSH .074) or for a set of variables ( $p=.239$ ). The values of the Beta coefficient indicate that there is a very small influence of leg muscles (ASLE -.296), slightly larger of shoulder girdle muscles (ASSH -.572), and almost no influence of the muscles of the upper arm (ASBI .031); none of them have any statistical significance. The values of the coefficient of determination agree with these results ( $R^2=.152$ ) and an adjusted coefficient of determination ( $R^2_{\text{adjust}}=.051$ ), which indicates a very small correlation with no statistical significance.

Table 2

*Descriptive statistics.*

Variables	MIN	MAX	RAN	ARM	STD	SKE	KUR	KS - Z	
								KS - Z	p
DVAL	10.10	13.80	3.70	11.93	0.87	0.04	-0.12	0.38	1.00
ASLE	341.00	2232.00	1891.00	856.72	406.69	1.64	3.61	0.98	0.30
RSLE	5.78	36.59	30.81	17.99	6.14	0.65	1.80	0.52	0.95
ASBI	129.00	659.00	530.00	281.97	116.75	1.49	2.77	0.79	0.56
RSBI	3.79	18.31	14.52	6.00	2.61	1.03	1.02	0.66	0.78
ASSH	32.00	231.00	199.00	113.38	46.44	0.49	0.15	0.47	0.98
RSSH	0.98	3.79	2.81	2.35	0.64	-0.60	0.99	0.91	0.37

*Legend: DVAL – final score on vault, ASLE – absolute leg muscle strength, RSLE – relative leg muscle strength, ASBI – absolute strength of the upper arm muscles, RSBI – relative strength of the upper arm muscles, ASSH – absolute strength of the shoulder girdle muscles, RSSH – relative strength of the shoulder girdle muscles, MIN – minimum value, MAX – maximum value, RAN – range, ARM – arithmetic mean, STD – standard deviation, SKE – skewness, KUR – kurtosis, KC-Z – Kolmogorov smirnov Z test, p – statistical significance of the KS-Z test*

The influence of relative strength in relation to the absolute is greater, but without statistical significance, both for each variable separately (RSLE .166, RSBI .544, RSSH .060) and for a set of variables ( $p=.258$ ). Beta coefficient values indicate a very small influence of the upper arm muscles (-.144), small influence of leg muscles (-.322) while the influence of the shoulder girdle muscles is larger (.525) and amounts to 52.5%. The values of the coefficient of determination ( $R=.146$ ) and the adjusted coefficient of determination ( $R^2_{\text{adjust}}=.044$ ) also support the previously mentioned results, which, as with absolute strength, indicate a very small correlation without statistical significance.

## DISCUSSION

The aim of this study was to examine the influence of absolute and relative strength of the leg, upper arm and shoulder girdle muscles on the success of performing vault with gymnasts aged 13 to 16 years. The results showed that although there is some influence of the abovementioned muscles, it is not statistically significant.

Table 3  
Regression analysis of absolute strength.

Variables	Beta	t	p	R <sup>2</sup>	R <sup>2</sup> <sub>adjust</sub>	Std. Err. Est.	F	p
ASLE	-.296	-1.081	.290					
ASBI	.031	-.133	.895	.152	.051	.843	1.498	.239
ASSH	-.572	1.862	.074					

Legend: ASLE – absolute leg muscle strength, ASBI – absolute strength of the upper arm muscles, ASSH – absolute strength of the shoulder girdle muscles, Beta – standardized values of the regression coefficient, t – standardized tests of the significance of the regression coefficient, p – the level of significance of the standardized regression coefficient, R<sup>2</sup> – coefficient of determination, R<sup>2</sup><sub>adjust</sub> – adjusted coefficient of determination, Std. Err. Est. – standard error estimate, F – significance test of multiple regression analysis, p – significance level of multiple correlation

Table 4  
Regression analysis of relative strength.

Variables	Beta	t	p	R <sup>2</sup>	R <sup>2</sup> <sub>adjust</sub>	Std. Err. Est.	F	p
RSLE	-.322	-1.427	.166					
RSBI	-.144	-.615	.544	.146	.044	.846	1.430	.258
RSSH	.525	1.969	.060					

Legend: RSLE – relative leg muscle strength, RSBI – relative strength of the upper arm muscles, RSSH – relative strength of the shoulder girdle muscles, Beta – standardized values of the regression coefficient, t – standardized tests of the significance of the regression coefficient, p – the level of significance of the standardized regression coefficient, R<sup>2</sup> – coefficient of determination, R<sup>2</sup><sub>adjust</sub> – adjusted coefficient of determination, Std. Err. Est. – standard error estimate, F – significance test of multiple regression analysis, p – significance level of multiple correlation

There are very few studies that deal specifically with this topic. In the first research by Paunovic et al. (2018), the authors examined the influence of the relative strength of different muscle groups on the results in all-around for gymnasts aged 14 to 16 years. It came up with results that are consistent with the results in this study. There is an influence of the relative strength of the leg muscles on the result in all-around, but it is not statistically significant and amounts to  $p=0.413$ , the upper arm muscle amounts to  $p=0.926$  and, as in this study, the impact of the shoulder girdle muscles was the greatest (Beta=0.499) but still with no statistical significance ( $p=0.653$ ). The results for the set of variables are also very similar to the results in this study ( $p=0.653$ ).

In another study, Paunovic et al. (2019) examined the influence of absolute and relative strength on the success of performing the floor exercise. On a sample of respondents aged 14 to 16 years, results were obtained that are similar to the results in this and the abovementioned study. Although there is an influence of absolute and relative strength, it is not statistically significant. For absolute strength, it is at the level of  $p=0.295$ , and for relative, at the level of  $p=0.284$ .

In research by Qomarrullah, Kristiyanto, Sugiharto and Hidayatullah (2018), there were two variables as in this study, the leg and the arm muscle. In a slightly younger sample of subjects (10 to 12 years), the obtained results indicate a statistically significant influence of the



above variables on the technique of performing the jump (leg muscle  $p < 0.01$ , arm muscle  $p < 0.01$ ), in contrast to this study where, although there is an influence, it is not statistically significant.

Strength in boys aged 13 and 16 can vary greatly due to this sensitive period of development. Respondents of this age were selected because they competed in the same category. The internship is related to the age of the respondents. But it is not uncommon for children with good predispositions, which starts with training later, to progress equally well or better than those who have a longer internship.

## CONCLUSION

Based on the obtained results, it can be concluded that strength, both absolute and relative, is not a decisive factor for success in performing vaults. Although gymnasts work out exclusively with their own weight, their relative strength is not crucial for success. This does not mean that strength is not important for success in gymnastics. Instead, the reason for the results obtained in this way should be sought in the age of the respondents. Namely, at this age, gymnasts perform elements that are more coordination-wise and technically demanding and require less strength. Given their age, this way of training and competition is justified since for many reasons, the development of strength can "wait" for a few more years.

The significance of this research is reflected in its determination of the influence of absolute and relative muscle strength of the muscles of the legs, upper arms and shoulder girdle on success in performing vault for gymnasts aged 13 to 16 years. Since a performance on the vault starts with a run-up towards the springboard, followed by the take-off with both feet from the springboard, then a support phase of take-off from the vault and finally landing on both feet, it can be said that the choice of muscle groups is justified.

Bearing in mind that gymnasts exercise only with their weight, without additional external load, it can be concluded that relative strength is crucial for success in artistic gymnastics. But other motor skills should not be disregarded, since artistic gymnastics is a very complex sport and does not tolerate well deficiencies in the development of any motor ability. Specifically, for a successful performance on the vault, the shoulder girdle muscles have the greatest influence (without statistical significance). The reason for the results obtained in this way lies in the fact that the flight phase and the landing phase depend on the support phase and the repulsion from the vault.

As there is a small number of studies that research the subject of this paper, regardless of the results obtained, this research represents a good foundation and basis for future studies of the absolute and relative strength in artistic gymnastics. It can also be used by trainers as a guide in the training process, as it indicates which muscle groups are most active on the specific apparatus.

## REFERENCES

- Atiković, A., Kazazović, E., Kamanješavić, E., & Nožinović-Mujanović, A. (2019). Estimation correlation of biomechanical parameters and vault start value in men's artistic gymnastics. *Sport Scientific and Practical Aspects - International Scientific Journal of Kinesiology*. 16(1), 25-30.
- Badric, M., Sporis, G., Trklja, E., i Petrovic, J. (2012). Trend razvoja motorickih sposobnosti učenika od 5. do 8. razreda. U: Findak, V. (ured.). *21. ljetna skola kineziologa republike Hrvatske* (str. 115-121), Zagreb: Hrvatski Kinezioloski Savez.
- Čeklić, U., & Šarabon, N. (2021). Comparison between gymnasts and non-gymnasts in isometric strength of the lower limbs. *Eur J Transl Myol*, 31(1), 9663.

Dallas, G., Kirialanis, P., Dallas, C., & Mellos, V. (2017). The effect of training in maximal isometric strength in young artistic gymnasts. *Science of Gymnastics Journal*. 9(1), 71-81.

Dopsaj, M. (2010). Karakteristike Ft krive: Analiticki i dijagnosticki znacaj u sportu. U: Stankovic, R. (ured.). *XIV Međunarodni naucni skup FIS Komunikacije u sportu, fizickom vaspitanju i rekreaciji* (str. 47-69), Nis: Fakultet Sporta i Fizickog Vaspitanja.

Findak, V. (1999). *Metodika telesne i zdravstvene kulture*. Zagreb: Skolska Knjiga.

Hwang, K., Kim, Y., Choi, D., & Choi, M. (2020). Dynamic modeling for the second flight phase of the yurchenko layout vault based on msc. Adams. *Science of Gymnastics Journal*. 12(2), 163-171.

Ilic, M. (1980). *Sportska gimnastika*. Beograd: NIP „Partizan“.

International Gymnastics Federation - FIG, (2017), *Code of points*.

Kochanowicz, A., Niespodzinski, B., Mieszkowski, J., Kochanowicz, K., & Sawczyn, S. (2018). The effect of gymnastic training on muscle strength and co-activation during isometric elbow and glenohumeral flexion/extension. *The Journal of Sports Medicine and Physical Fitness*, 58(7-8), 966-73.

Kukulj, M., Jovanovic, A., i Ropert, R. (1992). *Opsta antropomotorika*. Beograd: Fakultet fizicke kulture.

Kurelic, N., Momirovic, K., Stojanovic, M., Sturm, J., Radojevic, Dj., i Viskic-Stalec, N. (1975). *Struktura i razvoj morfoloskih i motorickih dimenzija omladine*. Beograd: Institut za naucna istrazivanja Fakulteta za Fizicko Vaspitanje.

Malacko, J., i Popovic, D. (2001). *Metodologija kineziolosko antropoloskih istrazivanja* (3. izd.). Leposavic: Fakultet za Fizicku Kulturu.

Milanovic, D. (2009). *Teorija i metodika treninga*. Zagreb: Kinezioloski Fakultet.

Nicin, Dj., i Kalajdzic, J. (1996). *Antropomotorika*. Novi Sad, Fakultet Fizicke Kulture.

Nicin, Dj. (2000). *Antropomotorika (teorija)*. Novi sad: Fakultet Fizicke Kulture.

Opavski, P. (1971). *Osnovi biomehanike*. Beograd: Naucna knjiga.

Paunovic, M., Velickovic, S., Đurovic, M., Okicic, T., Stojanovic, N., & Milosevic, N. (2018). Influence of relative force on all-around competition result with gymnasts. In: Kocic, M. (ed.), *XXI International Scientific Conference „Fis Communications 2018“ in physical education, sport and recreation* (pp. 48-51), Nis: Faculty of Sport and Physical Education.

Paunovic, M., Velickovic, S., Đurovic, M., Okicic, T., Antic, V., Milosevic, N., & Ostojic, S. (2019). Influence of strength of lower extremities on performance success on floor exercise. In: Stojiljkovic, N. (ed.), *XXII International Scientific Conference „Fis Communications 2019“ in physical education, sport and recreation* (pp. 49-54), Nis: Faculty of Sport and Physical Education.

Petkovic, D., Velickovic, S., Petkovic, E., Hadzi – Ilic, S., i Mekic, H. (2013). *Sportska gimnastika – I, teorija sportske gimnastike*. Nis: Fakultet Sporta i Fizickog Vaspitanja.

Petkovic, E. (2011). *Gimnastika za sve (generalna gimnastika)*. Nis: Fakultet Sporta i Fizickog Vaspitanja.

Prskalo, I. (2004). *Osnove kineziologije* (monografija). Petrinja: Visoka Uciteljska Skola.

Qomarrullah, R., Kristiyanto, A., Sugiharto., & Hidayatullah, M.F. (2018). Dominant factors of physical ability

determining the achievement of artistic gymnastic techniques. *International Conference on Science and Education and Technology (ASSEHR)*, 247, 395-399.

Scharer, C., Haller, N., Taube, W., & Hubner, K. (2019). Physical determinants of vault performance and their age-related differences across male junior and elite top-level gymnasts. *PLoS ONE*, 14(12), e0225975.

Scharer, C., Huber, S., Bucher, P., Capelli, C., & Hubner, K. (2021). Maximum strength benchmarks for difficult static elements on rings in male elite gymnastics. *Sports* 2021, 9(6), 78.

Scharer, C., Lehmann, T., Naundorf, F., Taube, W., & Hubner, K. (2019). The faster, the better? Relationships between run-up speed, the degree of difficulty (Dscore), height and length of flight on vault in artistic gymnastics. *PLoS ONE*, 14(03), e0213310.

Siff, M. (2001). Biomechanical foundations of strength and power training. In: Zatsiorsky V. (ed.), *Biomechanics in Sport – Performance Enhancement and Injury Prevention*, (pp. 103-139), London: Blackwell Science Ltd.

Stojiljkovic, S. (2003). *Osnove opste antropomotorike*. Nis: Fakultet Fizicke Kulture.

Stone, M. H. (1993). Position/policy statement and literature review for the National Strength and Conditioning Association on "Explosive Exercise". *National Strength and Conditioning Association Journal*, 15(4), 7-15.

Ugarkovic, D. L. (2004). *Biomedicinske osnove sportske medicine*. Novi Sad: FB print.

World Medical Association. (2013). Declaration of Helsinki. *Bulletin of the world health organization*, 79, 373-374.

Miloš Paunović  
Faculty of Sport and Physical Education  
University of Niš  
Čarnojevića 10a, Niš  
Tel.: +381654200831  
E mail: zuxxx123@gmail.com

Article received: 2.9.2021

Article accepted: 11.2.2022

### Corresponding author:

