RELATIONSHIP OF ABSOLUTE AND RELATIVE LOWER EXTREMITIES STRENGTH AND THE EFFICIENCY OF VAULT PERFORMANCE IN GYMNASTICS

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Abstract

The aim of this research was to examine the relationship between absolute and relative lower extremity strength and the efficiency of gymnastics vault performance. Thirty healthy, physically active male students (age: 20.84 ± 0.99 years; height: 179.46 ± 5.91 cm; body weight: 73.88 ± 6.43 kg) from the Faculty of Sports and Physical Education participated in the study. Absolute lower extremity strength was assessed by measuring the maximum load lifted (in kg) during a back squat (1RM). Relative lower extremity strength was calculated by dividing the estimated 1RM back squat by the participant's body weight (1RM/BW). Two types of vaults—the squat through (ST) and the front handspring (FHS)—were used to evaluate vault performance efficiency. Three criterion variables were applied: (d1) distance from the springboard in front of the vault, (d2) distance of landing beyond the vault, (d1 - d2) the difference between d1 and d2, and (pt) overall vault performance rating. The results showed statistically significant and strong correlations between both absolute and relative lower extremity strength and the variables measuring vault performance efficiency. The strongest correlations were observed for (d1), followed by (d2), (pt), and (d1 - d2). These findings can serve as guidelines for developing both absolute and relative lower extremity strength, which may lead to improved performance in gymnastics vaults.

Keywords: *absolute strength, relative strength, vaulting, artistic gymnastics.*

INTRODUCTION

Artistic gymnastics is a highly complex sport that involves bounding, jumping, tumbling, vertical landings, and rapid acceleration and deceleration movements. These actions result in high-impact loads, high strain rates, and varied strain distribution patterns on the skeleton (Farana, Jandacka, Uchytil, Zahradnik, & Irwin, 2014). As a competitive sport, artistic gymnastics requires athletes to meet high-performance standards and is characterized by dynamism, rhythm, and spectacular displays of acrobatic beauty and expressiveness (Mariana, Octavian, Daniela, & Iliana, 2016).

The vault is one of the apparatuses used in artistic gymnastics, requiring significant physical ability and performance

(Kochanowicz et al., 2016). Vaulting demands highly developed motor skills, and practicing vaults further enhances these skills. The movement pattern in vaulting improves a gymnast's speed, agility, muscle power, competitive drive, and courage (Arkaev & Suchilin, 2004). Experts emphasize the importance of factors such as run-up speed, maximal lower limb strength, the take-off angle from the springboard, and the orientation of anatomical segments and joint angles during hand contact with the vaulting table (Čuk et al., 2007; Kochanowicz et al., 2009).

Rapid position changes during each phase of the vault require gymnasts to have excellent timing, aerial awareness, and precise coordination of all involved body parts (Atiković & Smajlović, 2011; Koperski, Kochanowicz, & Słodkowski, 2010). Regardless of the vault's structure or complexity, each vault includes the following elements: the run-up, hurdling onto the springboard, the first phase of flight, the handspring off the vault, the second phase of flight, and the landing (Ferkolj, 2010). One key factor that distinguishes a gymnast's performance is the height achieved during these maneuvers, particularly vaulting. This elevation significantly impacts the judges' scoring, as highlighted by the research of Prassas, Kwon, and Sands (2006).

Vaulting is a dynamic activity performed in both men's and women's artistic gymnastics. Success in vaulting depends on a variety of factors, some independent and others within the gymnast's control. Each vault and group of vaults has a unique time structure and can be divided into seven phases. Some vaults require a faster run, while others need a slower one. Likewise, some vaults feature a long first flight phase, while others have a shorter one. In competition, gymnasts perform the most difficult vault they can safely execute.

As shown in Figures 1 and 2, each vault in the Code of Points (CoP) is divided into seven phases: (1) the run-up, (2) the jump onto the springboard, (3) springboard support and push-off, (4) the first flight phase (1stfp), (5) support and push-off from the table, (6) the second flight phase (2ndfp), and (7) the landing (Atiković & Smajlović, 2011; Čuk & Karacsony, 2004; Ferkolj, 2010; Prassas et al., 2006).

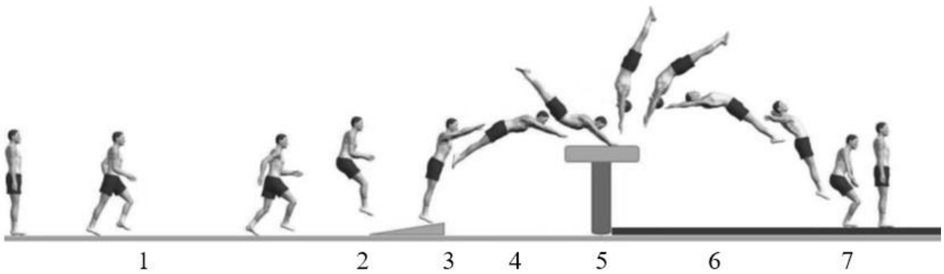

Figure 1. Vault seven phases (Atiković, 2012)

Strength is defined as a human trait, specifically the ability to overcome external resistance or oppose it through muscular effort (Nićin, 2000). The most common way to classify motor strength is by the ratio of force exerted relative to body mass. Strength can be categorized into two types: absolute strength, which is the maximum muscle strength a person can generate with their total muscle mass, and relative strength, which is the amount of strength a person can generate per kilogram of their body weight (Stojiljković, 2003).

Several authors have noted that the effectiveness of performing gymnastic exercises, including vaulting, depends not only on technical preparation but also on the gymnast's advanced psychomotor abilities and physical fitness (Zaporozhanov, Kochanowicz, & Kochanowicz, 2014). The body's vertical velocity at take-off and the net vertical impulse are key determinants of vault performance (Knudson, 2009), both of which strongly rely on segmental coordination and the application of proper technique (Bobbert, Huijing, & Schenau, 1987). A vault requires dynamic execution, achieving sufficient height and length. Gymnasts need more time to jump higher and move farther during the vault, which is associated with a higher technical level (Hashimoto, Noriyuki, & Nomura, 2017).

In their research, Atiković and Smajlović (2011) aimed to identify the biomechanical parameters that explain and define the difficulty level of a vault. Their predictor system of variables (R Square) explained 92% of the variance, while the correlation between the predictor variables and the criteria resulted in a multiple correlation coefficient of 0.96 (RO).

Schärer, Lehmann, Naundorf, Taube, and Hübner (2019) examined the relationships between run-up speed, degree of difficulty (D-score), height, and length of flight in vault performance for handsprings in artistic gymnastics. In male gymnasts, run-up velocity showed a significant correlation with the D-score, height, and length of flight, but only for Tsukahara and Yurchenko vaults. Atiković, Kazazović, Kamanješavić, and Mujanović (2019) investigated the correlation between biomechanical parameters and the vault start value in men's artistic gymnastics. Their research aimed to determine the relationship between the vault start value and key variables such as run-up velocity, first flight phase, table support, and second flight phase. According to their correlation matrix, the criteria variables from the Code of Points FIG MAG (2017-2020) showed a statistically significant positive correlation with two variables: run-up velocity on the springboard and the second flight phase. However, there was a negative correlation with two other variables: the first flight phase and vault support.

Paunović, Veličković, Okičić, Jović, and Đorđević (2022) analyzed the relationship between physical ability factors, such as running speed, leg muscle strength, arm muscle strength, abdominal muscle strength, and balance, in vault technique. The results indicated that while these muscles do have some influence, the effect is not statistically significant. Similarly, Paunović, Veličković, Đurović, Okičić, Stojanović, and Milošević (2018) examined the impact of relative strength in various muscle groups on all-around performance. Like the previous study, the relative strength of leg muscles showed some influence on all-around results, but it was not statistically significant. In another study, Paunović, Đurović, Veličković, Živković, and Stojanović (2019) explored the effect of absolute and relative strength on floor exercise performance. Their findings mirrored those of earlier studies, showing an influence of strength, but again, it was not statistically significant.

In the research conducted by Kochanowicz et al. (2016), the authors aimed to define the correlation between maximal power of the lower limbs in youth gymnasts, kinematic analysis of the front handspring vault, and sports results. The study found a strong correlation between the results from the countermovement jump and the scores for the front handspring vault, indicating a close relationship with maximal lower limb power. Additionally, the authors identified that the most significant correlations with the judges' scores for the front handspring vault were observed in the angle of the hip joint during the second phase of flight, the moment of touching the vault surface, the height of the second flight phase, and the landing distance.

In a separate study, Bradshaw and Le Rossignol (2004) investigated vaulting talent in young female gymnasts. They found that the best regression model for predicting vaulting talent included predictor variables such as resultant velocity at take-off from the springboard, squat jump power, and average power during the last five jumps in a continuous bent-leg jump series.

Koperski et al. (2010) defined the level of quickness-force abilities in athletes and examined the correlation between take-off performance in laboratory conditions and results in actual contests. Their study found that the parameters related to muscle work in the legs and hip area were strongly correlated with springboard take-off power. Similarly, research by Qomarrullah, Kristiyanto, Sugiharto, and Hidayatullah (2018) revealed that lower extremity muscle strength had the most significant effect on performance, while running speed had the least impact.

The main purpose of this research was to determine if there are statistically significant relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency among students. We anticipate that this study will encourage further scientific exploration into the areas of lower extremity strength and gymnastics vault performance. It is hypothesized that there are statistically significant relationships between both absolute and relative lower extremity strength and gymnastics vault performance efficiency, and that it will be possible to predict vault performance efficiency based on these strength measures

METHODS

The participant sample for this study consisted of thirty male students (n=30) from the Faculty of Sports and Physical Education at the University of Sarajevo, with a mean age of 20.84 ± 0.99 years, weight of 73.88 ± 6.43 kg, and height of 179.46 ± 5.91 cm. All procedures were conducted in accordance with the Declaration of Helsinki and the ethics committee standards of the Faculty of Sports and Physical Education at the University of Sarajevo.

The research was conducted at the end of the summer semester of the academic year. Throughout the summer semester, all participants attended regular practical classes in artistic gymnastics for 15 weeks, which included vaulting exercises as part of the curriculum. During these 15 weeks, students completed a total of 45 hours of practical training, focusing not only on vaulting but also on three other apparatuses. The attendance rate for these classes was 95%. Additionally, students participated in free gymnastics practice sessions scheduled three times a week, each lasting three hours.

The assessment of absolute and relative lower extremity muscle strength, as well as the evaluation of gymnastics vault performance, was carried out in the final, 15th week of the semester. Participants were thoroughly briefed on the research program before it began.

In this research, body height and weight for each participant were measured using an InBody BSM370 stadiometer (InBody Co.).

To assess absolute and relative lower extremity strength (see Table 1), the back squat test was utilized. The back squat involves positioning a barbell across the shoulders on the trapezius, just above the posterior aspect of the deltoids. The participant then slowly flexes their hips and knees until their thighs are parallel to the floor. They then extend their hips and knees to return to the starting position, ensuring that the back remains flat, the heels stay on the floor, and the knees remain aligned over the feet (Delavier, 2010).

Table 1
Variables for assessing absolute and relative lower extremity strength.

1RM (kg) - absolute lower extremity strength
1RM/BW - relative lower extremity strength

Absolute lower extremity strength was measured as the maximum load lifted during the back squat, expressed in kilograms (1RM). Relative lower extremity strength was calculated by dividing the estimated 1RM back squat by the participant’s body mass, resulting in (1RM/BW).

The protocol for assessing absolute and relative lower extremity strength was adapted from Kraemer, Fry, Ratamess, and French (1995). Participants began with a warm-up consisting of 8-10 repetitions with a light load (approximately 50% of the expected 1RM). This was followed by 3-5 repetitions with a moderate load (approximately 75% of the expected 1RM) and then 1-3 repetitions with a heavy load (approximately 90% of the expected 1RM). After warming up, participants attempted the 1RM test by progressively increasing the load until either their technique was significantly compromised or they could no longer lift a heavier weight. The load was increased by 2.5 to 5 kg with each attempt (Stone et al., 2003). A rest period of 5 minutes was observed between attempts.

To assess the efficiency of gymnastics vaults, two vaults that are part of the curriculum for the first cycle of studies at the Faculty of Sports were used. As shown in Figures 2 and 3, the success of performing the vault elements was evaluated using the following criteria: ST - squat through; FHS - front handspring vault.

The following variables were used to assess the gymnastics vaults performance efficiency (Table 2 and Figure 4).

Figure 2. ST - squat through (Atiković, Tabaković, Hmjelovjec, Kalinski, & Stoicescu, 2009).

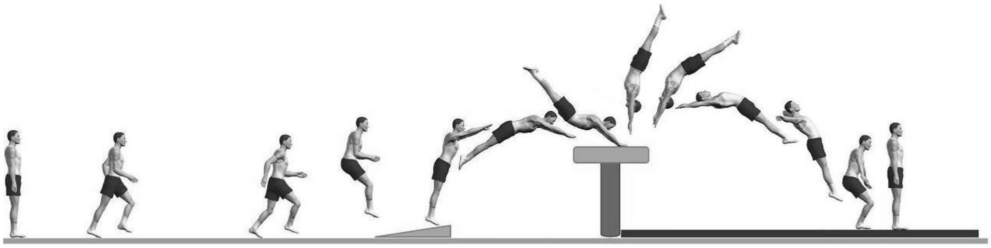

Figure 3. FHS - front handspring vault (Atiković, 2012).

Table 2
Variables for assessing the gymnastics vaults performance efficiency.

ST - squat through	d1(cm) - distance from the springboard in front of the vault d2 (cm) - distance of landing beyond the vault
FHS - front handspring vault	d1 - d2 (cm) - the difference between d1 i d2 pt (points) - overall vault performance rating

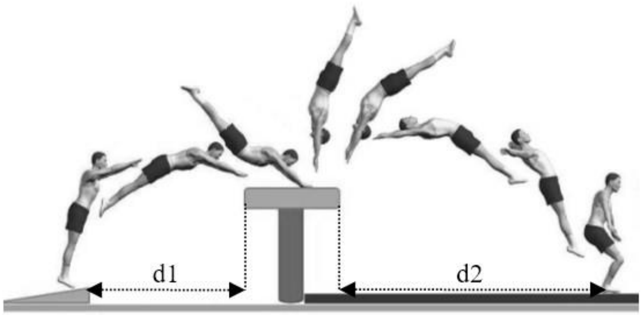

Figure 4. Characteristics of variables vaults prepared upon the Atiković (2012) scheme, being modified. All markings are approximate.

The variable (d1) is defined as the distance from the springboard take-off in front of the vault. Variable (d2) - defined as the distance of landing beyond the vault. Variable (pt) - overall vault performance rating, defined as the overall technical efficiency of the vault performance expressed in points.

At the beginning of the summer semester, participants had no prior knowledge of gymnastics vaults. By the 15th week of classes, an assessment of two gymnastics vaults, the ST (squat through) and FHS (front handspring) vaults, was conducted to evaluate performance efficiency. The final evaluation was carried out by experts (N = 4) from the University, each with over 20 years of experience working in various sports clubs and at the Faculty of Physical Education and Sports.

The assessment took place in a gym equipped with vaulting apparatuses, including a vault height of 135 cm and a maximum run-up distance of 25 m, using an "Elan" springboard for takeoff. To measure variable (d1) – the distance from the springboard to the vault – a measuring tape in centimeters was placed at the springboard location. Similarly, another measuring tape was placed on the landing mats to measure variable (d2) – the distance of landing beyond the vault. Prior to the evaluation, examiners reviewed the task descriptions and criteria outlined in Table 3. Each examiner assessed the participants independently during the exam, without communication with each other or revealing their assigned scores. The final evaluation of gymnastics vault performance efficiency was based on scores from judges (N = 3).

Table 3
Criteria for Gymnastics Vaults knowledge evaluation.

Measuring scale (points)	Description of standards - Gymnastics Vault
Points 6 or 6.5	The vault was executed with major errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Major errors may be evident in the aesthetic aspect of the vault, including the poor posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of major errors is 8 or more for a rating of 6, and 7 errors for a rating of 6.5.
Points 7 or 7.5	The vault was performed with errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. These errors may be present in the aesthetic aspect of the vault, including the poor posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of errors is 6 for a rating of 7, and 5 errors for a rating of 7.5.
Points 8 or 8.5	The vault was executed with minor errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Possible minor errors may be found in the aesthetic aspect of the vault, including slight deviations in the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of errors is 4 for a rating of 8, and 3 errors for a rating of 8.5.
Points 9 or 9.5	The vault was performed with minor errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. Possible minor errors may be present in the aesthetic aspect of the vault, including slight deviations in the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and landing. The maximum total number of minor errors is 2 for a rating of 9, and 1 error for a rating of 9.5.
Points 10	The vault was executed optimally without errors found in specific technical requirements concerning body position, as well as the positioning of legs and/or arms. There are no errors in the aesthetic aspect of the vault, including the posture of the entire body and/or individual body parts, coordination of performance, range of motion, speed, and the landing is secure.

The level of agreement among judges was assessed using Cohen's Kappa coefficient. The reliability coefficient among judges was .72, indicating a high level of agreement. However, upon reviewing individual agreement coefficients, it was found that one judge had a lower agreement coefficient compared to the other three judges. Consequently, the ratings from this judge were excluded from the final processing of the results.

The subjects performed both gymnastics vaults, the (ST) - squat through and (FHS) - front handspring, twice (see Table 2 and Figures 2, 3, 4). Only the better performance of each vault was used in the analysis. All thirty participants executed the vaults independently, without physical assistance. Students who could not perform the vault independently did not participate in the study. Judges recorded the following on the participant's card: (d1) - the distance from the springboard to the vault in centimeters, (d2) - the distance of landing beyond the vault in centimeters, and (pt) - the overall vault performance rating in points. Subsequently, the difference between (d1 - d2) was calculated in centimeters. The final evaluation for variable (pt) - overall vault performance rating was made using a scale from 6 to 10 points (see Table 3), according to the modified criteria by Tabaković, Tabaković, and Atiković (2023), where 10 points represented the highest rating. To better differentiate vault performances, judges could assign scores with half-point increments (e.g., 6.5; 8.5). The same procedure was followed by seven teachers, experts in the field of gymnastics, to set the criteria for optimal performance of a "handspring" vault (Milosis, Siatras, Proios, Proios, Christoulas, & Papaioannou, 2018). After evaluating the better performances, the final grade for each examinee for each task was calculated as the arithmetic mean of the scores assigned by the examiners

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. To determine the relationships between absolute and relative lower extremity strength and vault performance efficiency, Pearson's correlation coefficient (r) was applied. Regression analysis was employed to establish the prediction of vault performance efficiency based on absolute and relative lower extremity strength. For this purpose, the following were calculated: β - 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 - multiple regression; R^2 - coefficient of determination; R^2_adjusted - adjusted coefficient of determination; F - significance test of multiple regression analysis; and p - significance level of multiple correlation. The Shapiro-Wilk test was used to check the normality of the distribution.

RESULTS

The results of arithmetic means, standard deviations, and Pearson's correlation coefficients for absolute and relative lower extremity strength variables and variables measuring vault performance efficiency are presented in Table 4. For the variables assessing gymnastics vault performance efficiency, slightly higher mean values were obtained for the variable (d1) - distance from the springboard in front of the vault compared to variable (d2) - distance of landing beyond the vault. The normality of the distribution of results was confirmed by the Shapiro-Wilk and Kolmogorov-Smirnov tests, which yielded values greater than .05 for all applied variables.

Upon examining Pearson's correlation coefficient, statistically significant and high correlation values were observed at the significance levels (p = .01 and .05) between absolute and relative lower extremity strength variables and variables measuring gymnastics vault performance efficiency. The highest correlations were found with variable (d1) - distance from the springboard in front of the vault, followed by variables (d2) - distance of landing beyond the vault, and variable (pt) - overall vault performance rating.

The results of the regression analysis for gymnastic vaults (ST) - Squat Through and (FHS) - Front Handspring Vault are presented in Table 5. The predictor system of variables (1RM) - absolute lower extremity strength and (1RM/BW) - relative lower extremity strength, coefficient of determination explains the shared variability with the criterion variables in the range of (R^2 = 67%) to (R^2 = 45%), with a level of statistical significance (p = .00). The criterion variable (d1) - distance from the springboard in front of the vault had the highest shared variability with the predictor variables, followed by (d2) - distance of landing beyond the vault and (pt) - overall vault performance rating, but there was no statistically significant variability with the variable (d1 - d2) - the difference between d1 and d2. The values of adjusted coefficient of determination R^2_{adjust} ranged from (R^2_{adjust} = .64) to (R^2_{adjust} = .14). The values of multiple correlation coefficients R, which have levels of statistical significance at (p = .00), ranged in values from (R = .82) to (R = .68), representing a high value. Upon analysis of partial regression coefficients, β values, which have levels of statistical significance at (p = .00 and p = .01), it was observed that the predictor variable (1RM) - absolute lower extremity strength has statistically significant correlations with all criterion variables except for one correlation (d1 - d2) - the difference between d1 and d2. The correlation values range from (β = .68) to (β = .57). The predictor variable (1RM/BW) - relative lower extremity strength does not have statistically significant correlations with the criterion variables for vaults

Table 4
Arithmetic means, standard deviations, and Pearson's correlation coefficients of variables absolute and relative lower extremity strength and variables measuring the vaults performance efficiency

Variable	M ± SD		
1RM (kg)	89.67 ± 13.70		
1RM/BW	1.21 ± .19		
ST - squat through Variable	M ± SD	1RM r	1RM/BW r
d1(cm)	109.93 ± 12.36	.81**	.71**
d2 (cm)	101.33 ± 11.68	.74**	.68**
d1 - d2 (cm)	8.60 ± 3.16	.43*	.29
pt (points)	7.68 ± .70	.73**	.66**
FHS - front handspring vault Variable	M ± SD	1RM r	1RM/BW r
d1 (cm)	107.53 ± 13.24	.77**	.69**
d2 (cm)	97.77 ±11.23	.75**	.67**
d1 - d2 (cm)	9.77 ± 4.11	.40*	.35
pt (points)	7.28 ± .78	.67**	.61**

Data are presented as the M ± SD. r- Pearson's correlation. p- significance level of Pearson's correlation. **. The mean difference is significant at the .01 level. *. The mean difference is significant at the .05 level

Table 5
Regression analysis of vault ST - squat through and FHS - front handspring

Criterion Variables	Predictor Variables	β	t	p	R	R^2	R^2_{adjust}	F	p
d1 (cm)	1RM (kg) 1RM/BW	.68 .17	3.58 .88	.00 .39	.82	.67	.64	27.10	.00
d2 (cm)	1RM(kg) 1RM/BW	.56 .22	2.60 1.03	.01 .31	.75	.57	.53	17.66	.00
d1 - d2 (cm)	1RM(kg) 1RM/BW	.36 .17	1.23 .58	.22 .57	.41	.22	.14	3.29	.07
pt (points)	1RM(kg) 1RM/BW	.64 .04	2.63 .15	.01 .88	.72	.45	.41	11.07	.00
d1 (cm)	1RM (kg) 1RM/BW	.59 .21	2.79 1.01	.01 .32	.78	.59	.56	19.36	.00
d2 (cm)	1RM(kg) 1RM/BW	.57 .22	2.67 1.02	.01 .32	.74	.57	.54	18.20	.00
d1 - d2 (cm)	1RM(kg) 1RM/BW	.33 .09	1.09 .30	.28 .77	.40	.20	.16	2.63	.09
pt (points)	1RM(kg) 1RM/BW	.65 .15	2.99 .69	.01 .50	.68	.58	.55	16.44	.00

Data are presented as the β - 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 - Multiple correlation coefficients. R^2 - Coefficient of determination. R^2_{adjust} - Adjusted coefficient of determination. F - Significance test of multiple regression analysis. p - Significance level of multiple correlation

DISCUSSION

This research aimed to determine the relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency. The authors also sought to explore the possibility of predicting gymnastics vault performance efficiency based on absolute and relative lower extremity strength. The main finding of this research is that statistically significant relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency were observed in almost all variables. Based on the values of multiple correlations and partial regression coefficients, it is possible to successfully predict gymnastics vault performance efficiency using absolute and relative lower extremity strength.

The analysis of the arithmetic means, Pearson’s correlation coefficients, and regression analysis of variables measuring absolute and relative lower extremity strength, along with those assessing vault performance efficiency, yields the following discussion of results. The mean values for gymnastics vaults are slightly higher for the squat through vault compared to the front handspring vault, as expected, given the simpler motor structure of the squat through vault. Statistically significant and strong Pearson’s correlation values were obtained between absolute and relative lower extremity strength variables and vault performance efficiency. Regression analysis also revealed statistically significant and strong multiple correlations and partial regression coefficients, demonstrating a positive and significant influence of absolute and relative lower extremity strength on vault performance efficiency, as well as the potential to predict vault performance efficiency based on these strength measures.

The predictor variable (1RM) – absolute lower extremity strength – proved more effective in predicting vault performance efficiency based on partial regression coefficients. The highest values for the arithmetic means, Pearson’s correlation coefficients, and regression coefficients were found in the following criterion variables: (d1) – distance from the springboard in front of the vault, (d2) – landing distance beyond the vault, (pt) – overall vault performance rating, and (d1 - d2) – the difference between d1 and d2.

Based on these results, it can be concluded that participants performed vaults with a slightly greater distance from the springboard compared to the distance they achieved during the landing phase. This led to slightly lower final scores for overall vault execution. One possible reason for this performance outcome is that the college students had limited prior experience performing vaults, whereas elite gymnasts typically achieve a shorter difference between the takeoff and landing phases.

A small number of studies similar to this one exist. The following studies are presented as partial support for this research. Only the results and discussions from studies that partially confirm the findings of our study have been extracted.

Atiković and Smajlović (2011) found a statistically significant correlation between criterion variables from the COP matrix (FIG, 2009) and five variables: BCG velocity on the springboard ($r = 0.768$, $p < 0.05$), alpha in the x-axis during the second flight phase ($r = 0.759$, $p < 0.05$), and time of the first flight phase ($r = -0.486$, $p < 0.01$). Their analysis of the impact of individual variables showed the greatest and most statistically significant influence of criterion variables from the COP matrix on the following individual variables: alpha x during the second flight phase ($\beta = 0.835$, $p < 0.001$), alpha y during the second flight phase ($\beta = 0.375$, $p < 0.001$), and moment of inertia Jx in the second flight phase ($\beta = 0.373$; $p < 0.001$).

Farana and Vaverka (2012) reported that five out of 23 examined variables showed significant correlations with the scores. Significant correlations were found in the vertical height of the body mass center during take-off from the vaulting table ($r = 0.86$), the maximum height of the body mass center in the second flight phase ($r = 0.83$), the horizontal velocity change during the take-off phase from the vaulting table ($r = -0.69$), the horizontal velocity component during take-off from the vaulting table ($r = 0.75$), and the duration of the second flight phase ($r = 0.69$).

The significance of the research by Paunović et al. (2022) lies in determining the influence of absolute and relative muscle strength in the legs, upper arms, and shoulder girdle on the success of vault performance. While the influence of relative strength compared to absolute strength is greater, it does not reach statistical significance. Based on the results, it can be concluded that neither absolute nor relative strength is a decisive factor for vault success. Specifically, the muscles of the shoulder girdle have the greatest influence on vault performance, although this influence is not statistically significant. The beta coefficient values indicate a very small influence from the upper arm muscles (-.144) and a small influence from the leg muscles (-.322), while the shoulder girdle muscles have a larger influence, contributing 52.5% ($\beta = .525$).

In Paunović et al. (2018), the authors examined the influence of the relative strength of different muscle groups on the all-around performance of gymnasts aged 14 to 16. While relative strength of the leg muscles influences all-around results, this influence is not statistically significant ($p = 0.413$). Similarly, the influence of the upper arm muscles was not significant ($p = 0.926$). As in the previous study, the shoulder girdle muscles had the greatest influence ($\beta = 0.499$), though still not statistically significant ($p = 0.653$). The results for this set of variables closely mirror those from the earlier study.

In another study, Paunović et al. (2019) examined the influence of absolute and relative strength on the success of performing the floor exercise. Using a sample of respondents aged 14 to 16 years, the results were similar to those of previous studies. While both absolute and relative strength showed influence, it was not statistically significant. For absolute strength, the significance level was (p =

0.295), and for relative strength, it was ($p = 0.284$).

Čuk and Karacsony (2004) presented the biomechanical characteristics of vaulting, identifying the most important factors for successful vaulting, such as morphological characteristics, run velocity, length of flight on the springboard, duration of board contact, foot position relative to the springboard edge, duration of the first flight phase, duration of table support phase, duration of the second flight phase, jump height, moments of inertia on the x and y axes, distance during the second flight phase, and landing.

A gymnastics vault clearly reflects the specificity of effort, which is influenced by various manifestations of dynamic strength. This strength is primarily evident during the take-off from the springboard through the lower extremities, and during the take-off from the apparatus through the upper extremities. Static strength, which opposes dynamic strength, is demonstrated during landing (Kochanowicz et al., 2009).

According to research conducted by Marinšek (2010), the physical preparation and motor control of gymnasts are determining factors for all phases of vault exercises in artistic gymnastics, including the run-up, jump onto the springboard, springboard support phase, first flight phase, and landing.

In the study conducted by Koperski et al. (2010), the highest and most statistically significant correlation between gymnasts' results in take-off power, assessed on a tensiometric platform and the springboard, was ($r = 0.916$) at ($p \leq 0.05$). Additionally, a crucial correlation was observed between the time of the contestant's contact with the ground during laboratory tests and the same parameter measured during take-off from the springboard ($r = 0.668$). The analysis of test results reveals a strong correlation between athletes' speed and force abilities in laboratory conditions and the physical values exhibited during springboard take-off in actual competition. Therefore, the measurement of speed-force abilities (take-off power) in laboratory conditions can be an effective measure of athletes' preparedness for gymnastic vaults.

Previous research by Kochanowicz and Kochanowicz (2014) demonstrated that vault performance effectiveness is influenced by somatic features, motor abilities, and technical skills. In a later study by Kochanowicz et al. (2016), mean values of lower limb power indicators and their correlation with the vault score were as follows: maximal power (W) 1400.91 ± 502.74, ($r = 0.401$*); relative maximal force (%BW) 234.87 ± 34.34, ($r = 0.330$*). Additionally, mean values of biomechanical indicators and their correlation with the score for the front handspring vault were: d0 (springboard distance before the vault) 96.64 ± 22.78 cm, ($r = 0.441$*), and d3 (landing distance) 138.73 ± 45.79 cm, ($r = 0.631$**).

Testing of the second hypothesis on the influence of leg muscle strength on vault technique yielded a significant result ($r = 0.000$, $p < 0.01$). The influence ($\lambda = X^2 \rightarrow Y$) belongs to the medium category, with the most significant impact on the correlation value of 0.454. The movement of the lower extremities during the run-up to the round-off position and the landing point at the fulcrum is driven by leg muscle strength. Leg muscle strength contributes to the power of foot jumps, while maximal explosive muscle strength enhances acceleration capabilities (Qomarrullah et al., 2018).

Several factors contributed to the relationships identified between absolute and relative lower extremity strength and gymnastics vault performance efficiency in this research, including the participant sample. The participants were students who had no significant prior knowledge of gymnastics vaults. After 15 weeks of regular gymnastics classes, the students gained knowledge of vaulting, which correlated significantly with their absolute and relative lower extremity strength.

Another contributing factor was the selection of variables. Different results might have been observed if the study had included additional variables to assess muscle strength in the arms, shoulder girdle, or other motor abilities influencing vaulting efficiency. A third factor was the inclusion of both the squat through and front handspring vaults, as well as the criterion variables used to evaluate vaulting efficiency. Although not highly complex in movement structure, both vaults are challenging for students, with those displaying higher levels of absolute and relative lower extremity strength achieving more successful performances.

Absolute and relative lower extremity strength had the greatest impact on the criterion variables for vaulting: (d1) - the distance from the springboard ahead of the vault, followed by (d2) - the distance of landing behind the vault, and (pt) - overall vault performance rating.

From the foregoing, this research has some limitations in terms of theoretical and practical usefulness. These limitations are reflected in the fact that the results of our study can primarily be applied to students at sports faculties and beginners in artistic gymnastics and, therefore, cannot be generalized or applied to elite gymnasts. Additionally, one of the limitations is that, aside from absolute and relative strength, other factors crucial for vaulting efficiency, as mentioned earlier, were not addressed in this study.

CONCLUSION

This study investigated the relationships between absolute and relative lower extremity strength and gymnastics vault performance efficiency. Significant statistical relationships between absolute and relative lower extremity strength and vaulting efficiency were found in almost all variables examined. The prediction of vaulting efficiency based on these strength measures can be successfully determined using multiple correlations and partial regression coefficients.

We hope this study stimulates future scientific research on the role of lower extremity strength in gymnastics vaulting. The value of this research lies in its potential to highlight the importance of enhancing absolute and relative lower extremity strength in sports gymnastics classes at sports faculties, making it easier for students and individuals without prior vaulting experience to learn and improve their vaulting performance. Future studies could investigate gymnasts performing more complex vaults, incorporating a wider range of strength-related variables and a more comprehensive set of vaulting efficiency measures

REFERENCES

Arkaev, L., Suchilin, N., & Suchilin, N. G. (2004). *Gymnastics: how to create champions*. Meyer & Meyer Verlag.

Atiković, A. (2012). New regression models to evaluate the relationship between biomechanics of gymnastic vault and initial vault difficulty values. *Journal of Human Kinetics*, *35*, 119-126. https://doi.org/10.2478/v10078-012-0085-6

Atiković, A., Kazazović, E., Kamanješavić, E., & Mujanović, A. (2019). Estimation correlation of biomechanical parameters and vault start salue in men's artistic gymnastics. *Sport Scientific and Practical Aspects-International Scientific Journal of Kinesiology*, *16*(1), 25-30.

Atiković, A., & Smajlović, N. (2011). Relation between vault difficulty values and biomechanical parameters in men's artistic gymnastics. *Science of gymnastics journal*, *3*(3), 91-105. https://www.dlib.si/details/URN:NBN:SI:DOC-BC64UZVA

Atiković, A., Tabaković, M., Hmjelovjec, I., Kalinski, S., & Stoicescu, M. (2009). Differences between vaults during the qualification C1 Aarhus 2006-39th men's & 30th women's artistic gymnastics world championship. *Revista Discobolul*. https://www.researchgate.net/publication/315714655_DIFFERENCES_BETWEEN_VAULTS_DURING_THE_QUALIFICATION_C1_AARHUS_2006-

39_TH_MEN'S_30_TH_WOMEN'S_ARTISTIC_GYMNASTICS_WORLD_CHAMPIONSHIPS

Bobbert, M. F., Huijing, P. A., & Schenau, G. J. v. I. (1987). Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Medicine & Science in Sports & Exercise*, *19*(4), 332-338.

Bradshaw, E. J., & Le Rossignol, P. (2004). Anthropometric and biomechanical field measures of floor and vault ability in 8 to 14 year old talent-selected gymnasts. *Sports Biomech*, *3*(2), 249-262. https://doi.org/10.1080/14763140408522844

Čuk, I., Bricelj, A., Bučar, M., Turšič, B., & Atiković, A. (2007). Relations between start value of vault and runway velocity in top level male artistic gymnastics. Proceedings Book of 2rd International Scientific Symposium, Sarajevo,

Čuk, I., & Karacsony, I. (2004). *Vault: methods, ideas, curiosities, history*. ŠTD Sangvinčki. https://books.google.ba/books?id=uXVaAAAACAAJ

Delavier, F. (2010). *Strength training anatomy*. Human Kinetics. https://books.google.ba/books?id=GgLGWbv763EC

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D., & Irwin, G. (2014). Musculoskeletal loading during the round-off in female gymnastics: the effect of hand position. *Sports Biomechanics*, *13*(2), 123-134. https://doi.org/10.1080/14763141.2014.895034

Farana, R., & Vaverka, F. (2012). The effect of biomechanical variables on the assessment of vaulting in top-level artistic female gymnasts in World Cup competitions. *Acta Gymnica*, *42*(2), 49-57.

Ferkolj, S. M. (2010). A kinematic analysis of the handspring double salto forward tucked on a new vaulting table. *Science of gymnastics journal*, *2*(1), 35-46. http://www.dlib.si/details/URN:NBN:SI:doc-TDL7WOH8

Hashimoto, M., Noriyuki, K., & Nomura, T. (2017). Characteristics of women's rhythmic gymnastics from the perspective of "body difficulty" and performance time. *Advances in Physical Education*, *07*, 260-273. https://doi.org/10.4236/ape.2017.73021

InBody Co., Ltd. . *BSM 370*. Retrieved 24.08. from https://www.inbody.in/product-page.php

Knudson, D. V. (2009). Correcting the use of the term "power" in the strength and conditioning literature. *The Journal of Strength and Conditioning Research*, *23*(6), 1902-1908. https://doi.org/10.1519/JSC.0b013e3181b7f5e5

Kochanowicz, A., Kochanowicz, K., Niespodziúski, B., Mieszkowski, J., Aschenbrenner, P., Bielec, G., & Szark-Eckardt, M. (2016). Maximal Power of the Lower Limbs of Youth Gymnasts and Biomechanical Indicators of the Forward Handspring Vault Versus the Sports Result. *Journal of Human Kinetics*, *53*(1), 33-40. https://doi.org/doi:10.1515/hukin-2016-0008

Kochanowicz, A., Kochanowicz, K., & Sawczyn, S. (2009). Special Fitness and the Effectiveness of Technical Preparation in Gymnastic Vault Event in Athletes at the Directed Stage. *Baltic Journal of Health and Physical Activity*, *1*, 70-78. https://doi.org/10.2478/v10131-009-0008-7

Kochanowicz, K., & Kochanowicz, A. (2014). Somatic characteristics of young gymnasts in the system of special sports training. *Theory and Practice of Physical Culture*, 31-34.

Koperski, A., Kochanowicz, A., & Słodkowski, C. (2010). Gymnasts' special quickness-force abilities and the indicators of jump from a springboard. *Baltic Journal of Health and Physical Activity*, *2*. https://doi.org/10.2478/v10131-0014-9

Kraemer, W. J., Fry, A. C., Ratamess, N., & French, D. (1995). Strength testing: development and evaluation of methodology. *Physiological assessment of human fitness*, *2*, 119-150.

Mariana, F., Octavian, V., Daniela, C., & Iliana, V. (2016). Music and the artistic rhythm-psychosomatic implications. *Ovidius University Annals, Series Physical Education and Sport/Science, Movement and Health*, *16*(1), 126-131.

Marinšek, M. (2010). Basic landing characteristics and their application in artistic gymnastics. *Science of gymnastics journal*, *2*. https://www.researchgate.net/publication/265995608_Basic_landing_characteristics_and_their_application_in_artistic_gymnastics

Milosis, D., Siatras, T., Proios, M., Proios, M., Christoulas, K., & Papaioannou, A. (2018). Accuracy of university students' skill-specific self-efficacy and self-efficacy-performance in gymnastics relationship. *International journal of sport psychology*, *49*. https://doi.org/10.7352/IJSP2018.49.429

Paunović, M., Đurović, M., Veličković, S., Živković, M., & Stojanović, N. (2019). The explosive strength of girls of the younger school age. *Facta Universitatis, Series: Physical Education and Sport*, 677-685. https://doi.org/10.22190/FUPES171022046P

Paunović, M., Veličković, S., Đurović, M., Okičić, T., Stojanović, N., & Milošević, N. (2018). Influence of relative force on all-around competition result with gymnasts. XXI International Scientific Conference „Fis Communications,

Paunović, M., Velikčković, S., Okičić, T., Jović, S., & Đorđević, D. (2022). The influence of strength on the gymnasts'success in performing vault. *Science of gymnastics journal*, *14*(2), 173-183. https://doi.org/https://doi.org/10.52165/sgj.14.2.173-183

Prassas, S., Kwon, Y. H., & Sands, W. A. (2006). Biomechanical research in artistic gymnastics: a review. *Sports Biomechanics*, *5*(2), 261-291. https://doi.org/10.1080/14763140608522878

Qomarrullah, R., Kristiyanto, A., Sugiharto, M., & Hidayatullah, M. F. (2018). Dominant factors of physical ability determining the achievement of artistic gymnastic techniques. International Conference on Science and Education and Technology 2018 (ISET 2018),

Schärer, C., Lehmann, T., Naundorf, F., Taube, W., & Hübner, K. (2019). The faster, the better? Relationships between run-up speed, the degree of difficulty (D-score), height and length of flight on vault in artistic gymnastics. *PloS one*, *14*(3), e0213310. https://doi.org/10.1371/journal.pone.0213310

Stojiljković, S. (2003). *Osnove opšte antropomotorike*. Studentski kulturni centar.

Stone, M. H., O'bryant, H. S., McCoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *The Journal of Strength & Conditioning Research*, *17*(1), 140-147.

Tabaković, A., Tabaković, M., & Atiković, A. (2023). The effects of 12-week isokinetic training on knee stabilizers strength and the efficiency of the performance of gymnastics vaults. *Science of gymnastics journal*, *15*(2), 239-256. https://doi.org/https://doi.org/10.52165/sgj.15.2.239-256

Zaporozhanov, V., Kochanowicz, K., & Kochanowicz, A. (2014). Improvement of comprehensive assessment of specially trained childhood and adolescence gymnasts. *Pedagogics, psychology, medical-biological problems of physical training and sports*, *18*(10), 3-7. https://doi.org/https://doi.org/10.5281/zenodo.10482

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