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THE POSSIBILITY OF PREDICTING JUMP HEIGHT BASED ON THE ABSOLUTE AND RELATIVE STRENGTH OF THE LOWER EXTREMITIES

Original research

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ABSTRACT
The aim of the research was to determine the possibility of predicting vertical jump height based on absolute and relative lower extremity strength. Thirty healthy and 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 this study. Absolute lower extremity strength was assessed using the one-repetition maximum (1RM) back squat, expressed in kilograms. Relative lower extremity strength was calculated by dividing the estimated 1RM back squat by the participants' body weight, yielding the 1RM back squat relative to body weight (BW) (1RM/BW). Vertical jump height was measured using an Optojump system with two types of jumps: countermovement jumps (CMJ) and squat jumps (SJ). Statistically significant and moderately high correlations were observed between absolute and relative lower extremity strength variables and vertical jump height variables. Regression analysis results indicated statistically significant multiple correlations of 1RM absolute strength and 1RM/BW relative lower extremity strength as predictors of CMJ and SJ vertical jump height criteria variables. There is limited research on this topic conducted specifically on student populations, making this study a valuable foundation for future research. The research findings can serve as guidelines for the development of absolute and relative lower extremity strength, thereby contributing to improved vertical jump performance.

Keywords: jump height, absolute strength, relative strength

INTRODUCTION

The ability to generate skeletal muscle power is a well-known predictor of sport performance (Garhammer & Gregor, 1992). However, direct measurement is difficult and often unfeasible, especially for coaches. The vertical jump (VJ) test is most commonly used as an indirect measure of leg power. Power and jumping are not identical (Cronin & Sleivert, 2005; Knudson, 2009), yet correlations link them to success in a variety of sports as rugby, volleyball, etc. (Baker & Newton, 2008; Sheppard et al., 2008).

High levels of muscle power in the lower extremities play an important role in several sports, as evidenced in speed running (Harrison et al., 2004; Loturco et al., 2015; Pupo et al., 2012; Smirniotou, 2008), in decisive moments of team sports jumps, kicks, and sprints (Castagna & Castellini, 2013; Dal Pupo et al., 2010; Sattler et al., 2015), and during the attack and defense actions in combat sports (Lima Kons et al., 2017; Zangelidis et al., 2012), etc. The vertical jump has been the most frequently and routinely used test for evaluating the lower limb power output of athletes (Castagna & Castellini, 2013; Kraska et al., 2009; Pazin et al., 2013). The jump height (JH) and power output are considered the main indicators of muscle power levels in the lower extremities (Knudson, 2009; Markovic & Jaric, 2007).

Due to their practical and timesaving characteristics, vertical jumps (VJ) are extensively used to assess power-related capabilities in top-level athletes. To some extent, this may be explained by the high values of association found between vertical jumping measures and a number of sport-specific motor tasks in individual and team sports (Loturco et al., 2015; Smirniotou, 2008). In some studies, moderate to very large correlations have been reported for absolute strength measures with squat jump (SJ) and countermovement jump (CMJ) height, respectively (Boraczyński et al., 2020; Comfort et al., 2014; Keiner et al., 2021; Rodríguez-Rosell et al., 2017; Wisloeff et al., 1998; Wisløff et al., 2004). Loturco et al. (2021) found large correlations between squat and countermovement jump height, 30-m sprint performance and maximum strength expressed relative to body mass, but nonsignificant correlations in absolute terms.

Squat strength relative to the body mass showed mostly moderate to large correlations with sprint performances, squat jump, and countermovement jump height, respectively (Boraczyński et al., 2020; Comfort et al., 2014; Keiner et al., 2014). A significant relation has been observed between one repetition maximum (1RM) and acceleration and movement velocity (Buhrle & Schmidtbleicher, 1977). This maximal strength/power performance relation is supported by results from both jump and 30 m sprint tests (Schmidtbleicher, 1992).

De Hoyo et al. (2016) and Hammami et al. (2018) discovered that maximal strength, as measured by the one-repetition maximum (1RM) back squat, was highly correlated with improved sprint performance, change of direction speed, and vertical jump height in adolescent male soccer players.

Significant correlations between 1RM back squat strength and sprint performance, vertical jump height, and aerobic endurance in elite male soccer players was reported in numerous studies (Stølen et al., 2005; Turner & Stewart, 2014; Wisløff et al., 2004).

In the study by Andersen et al. (2018) relative strength was calculated based on the estimated 1RM back squat divided by the athlete's body mass. Relative lower-body strength showed significant correlations with vertical jump. The study conducted by authors Wagner et al. (2023) showed significant moderate to large correlations for relative strength and sprint and jump performances, nonexistent to weak correlations were found between absolute strength and sprint and jump performances.

As can be inferred from the provided information, the majority of previous studies have focused on the relations between absolute and relative lower extremity strength and vertical jump height among selected athletes in specific sports. There are no significant studies, as in this research, that have examined the relationships between absolute and relative lower extremity strength and vertical jump height among a population of students engaged in various sports and physical activities. The main purpose of this study was to determine the potential for predicting vertical jump performance based on absolute and relative lower extremity strength among students. We anticipate that this study will stimulate interest in future scientific research in the areas of lower extremity strength. Our research assumes that there are statistically significant relationships between absolute and relative lower extremity strength and vertical jump height.

METHODS

Participants

The sample of participants for this study consisted of thirty students (n=30) of the Faculty of Sports and Physical Education at the University of Sarajevo, (mean age 20.84 ± 0.99 years, weight 73.88 ± 6.43 kg, height 179.46 ± 5.91 cm). All procedures were conducted in accordance with the Declaration of Helsinki. All participants attended regular practical classes at the faculty during the 15-week summer semester of the academic year. Testing of absolute and relative lower extremity strength, as well as vertical jump height tests, was conducted during the final 15th week of classes. Prior to commencement, research participants were thoroughly briefed on the research protocol. In this research, body height and weight were measured for each participant using an InBody BSM370 stadiometer (InBody Co.).

Measures and procedures

For the assessment of absolute and relative lower extremity strength (Table 1 and Figure 1), the back squat test was used in this study. The back squat involves positioning the barbell across the shoulders on the trapezius, slightly above the posterior aspect of the deltoids, and slowly flexing the hips and knees until the thighs are parallel to the floor (Delavier, 2010). The individual then extends the hips and knees until reaching the beginning (starting) position, with emphasis on keeping the back flat, the heels on the floor, and the knees 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

For the assessment of absolute and relative lower extremity strength, the following variables were used (Table 1).

Absolute lower extremity strength was measured based on the maximum load lifted expressed in kg during the back squat (1RM). Relative lower extremity strength was calculated based on the estimated (1RM) back squat divided by the body mass of the participants, that is, (1RM) back squat relative to the body weight (BW) of the participants (1RM/BW).

The protocol used to assess absolute and relative lower extremity strength in this study was described by Kraemer et al. (1995). Participants performed a warm-up of 8-10 repetitions with light load (approximately 50% of the expected 1RM). Then they executed 3-5 repetitions with a "moderate" load (approximately 75% of the expected 1RM), followed by 1-3 repetitions (approximately 90% of the expected 1RM). After the warm-up, participants attempted the 1RM test by increasing the load until the technique of performing the back squat was significantly compromised or the participant could not lift a heavier weight. During the test, the load was increased by 2.5 - 5 kg with each attempt (Stone et al., 2003). The rest period between the two attempts was 5 minutes.

Figure 1. Back squat (Tabakovic, 2023)

For the assessment of vertical jump height (Table 2 and Figure 2), this study utilized the Optojump Next system (Microgate, Bolzano, Italy) to measure two types of jumps: Countermovement jumps (CMJ) and Squat jumps (SJ). Countermovement jump (CMJ) is a vertical jump with momentum (test-retest correlation $r=0.94$, $p< 0.01$). The jump is initiated from an upright position, and the centre of the body is lowered until the knees are bent at a 90° angle. Then, the extension of the hip and knees begins. Squat jump (SJ): The SJ is a vertical jump from the crouch position without momentum (test-retest correlation $r=0.87$, $p<0.01$). The knees bend in a 90° position, the body is upright and the hands remain fixed to the hips (Keiner et al., 2015).

The following variables were used to estimate jump height (Table 2).

Table 2. Variables for assessing jump height.

CMJ (cm)	Countermovement jumps
SJ (cm)	Squat jumps

The protocol used to assess jump height in this study was described by Keiner et al. (2015). Squat jumps and countermovement jumps were tested using an Optojump. To ensure adequate familiarization, the participants were granted 3 test trials for each jump type. After that, the participants completed 5 trails of each jump, with a 1-minute rest between jumps. All jumps were performed with hands fixed on the hips throughout the whole measurement. The best result was used for statistical analysis. A successful squat jump was initiated from squat position (approx. 90° knee angle) after a 2-second hold without momentum. The countermovement jump utilizes the momentum of a preceding squat movement (to approx. 90° knee angle) to initiate the immediate jump. Correct movement execution was visually assessed and verbally reinforced by the investigators while the subjects were jumping.

Figure 2. Jump height (Tabakovic, 2023)

Statistical analysis

The Statistical Package for the Social Sciences (SPSS), version 21.0 (SPSS Inc., Chicago, Illinois) was used for data processing. Descriptive statistics (minimum, maximum, mean value and standard deviation) were calculated for all variables. To determine the relations between absolute and relative lower extremity strength and the height of the jump, Pearson's correlation coefficient (r) was applied. In order to determine the prediction of the height of the jump based on the absolute and relative strength of the lower extremities, a regression analysis was used. The Shapiro-Wilk test was used to check the normality of the distribution with significance levels annotated for p-values less than 0.05.

RESULTS

The results of minimum, maximum, arithmetic means and standard deviations, and of variables absolute and relative lower extremity strength and variables measuring the jump height are presented in Table 3.

Table 3. Descriptive Statistics

Variable	Minimum	Maximum	M ± SD
1RM	60.00	110.00	89.67 ± 13.70
RMTT	.86	1.75	1.21 ± .19
CMJ	27.90	51.20	37.64 ± 6.19
SJ	25.80	50.80	35.59 ± 6.15

Data are presented as the M ± SD = Arithmetic mean ± Standard deviation

The variables representing vertical jump height have consistent values. The normality of the distribution of results was confirmed by Shapiro-Wilk and Kolmogorov-Smirnov tests, which yielded values greater than .05 for all applied variables.

Upon examining the Pearson's' correlation coefficient (Table 4.), it is observed that statistically significant correlation values were obtained at the level of significance (p = .01 and p = .05), between absolute and relative lower extremity strength variables and variables measuring the jump height. The correlation values are moderately high, ranging from .39 to .48.

Table 4. Pearson's correlation coefficients

Variable		1RM	RM/BW
CMJ	r	.42*	.48**
	p	.02	.00
SJ	r	.39*	.45*
	p	.03	.01

Data are presented as the 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 4 displays the predictor system variable values for the criterion variables Countermovement jumps (CMJ) and Squat jumps (SJ), along with the corresponding levels of statistical significance (CMJ p = .04). The coefficient of determination values (CMJ R2 = 23% and SJ R2 = 20%) indicate the proportion of shared variability explained by the predictor variables regarding the criterion. The multiple correlation coefficients range in values (CMJ R = .48 and SJ R = .45), representing a medium high value.

Through the analysis of partial regression coefficients Beta, it can be observed that statistically significant values were not obtained.

Table 5. Regression analysis of Criterion Variables Countermovement jumps (CMJ) and Squat jumps (SJ)

Predictor Variables	Beta	t	p	R^2	R^2Adjust	R	p
1RM (kg) 1RM/BW	.09 .40	.31 1.40	.76 .17	.23	.17	.48	.04
1RM(kg) 1RM/BW	.07 .40	.23 1.36	.82 .19	.20	.15	.45	.05

Data are presented as the 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^2 - Coefficient of determination. R^2 adjust - Adjusted coefficient of determination. R- Multiple regression coefficient. p – Significance level of multiple correlation

DISCUSSION

The aim of this research was to determine the possibility of predicting vertical jump performance based on absolute and relative lower extremity strength. Furthermore, the study's objective was to determine the correlations between vertical jump height and both absolute and relative lower extremity strength.

The possibility of predicting vertical jump height is the main finding of this study, and it is based on both absolute and relative lower extremity strength. This prediction can be successfully established through the values of multiple correlations. Additionally, statistically significant relationships between absolute and relative lower extremity strength and vertical jump height were identified.

The mean values of the variables Countermovement jumps (CMJ) and Squat jumps (SJ) are consistent.
Statistically significant and moderately high correlation values were obtained between absolute and relative lower extremity strength variables and vertical jump variables. The variable used to assess relative strength (1RM/BW) demonstrates slightly higher correlations with variables assessing jump height compared to the variable assessing absolute strength (1RM). This observation can be explained by the established notion that the capacity to generate maximum ground reaction forces within a brief ground contact period to propel one's body mass is a pivotal factor influencing speed-strength performance (Hunter et al., 2005; Morin et al., 2012; Weyand et al., 2010)T. herefore, according to Newton's second law (force = mass * acceleration), athletes who can exert greater force relative to their own body mass should be able to accelerate more rapidly. With absolute values, these relationships between force, mass, and acceleration are not taken into consideration (Wagner et al., 2023). It can be concluded that participants with higher absolute and relative lower extremity strength achieved better vertical jump results.

Through regression analysis, statistically significant and moderately high multiple correlations were obtained, indicating the possibility of successful prediction of vertical jump results based on the predictor system variables of absolute and relative lower extremity strength. However, it is not possible to establish the prediction of vertical jump results based on partial regression coefficients with the predictor variables of absolute strength (1RM) and relative strength (1RM/BW) of the lower extremities. Supporting the findings of this study, there are several research works that have partially addressed similar issues.

Boraczyński et al. (2020) reported small to moderate correlations between absolute squat strength, short sprint (LS 5m) (r= |0.28|), and countermovement jump performance (r= |0.39|), but strong correlations between relative strength short sprint performance (r= |0.51|), and countermovement jump height (r= |0.60|).

Similarly, Loturco et al. (2021) found large correlations (r= |0.54| to |0.60|) between squat and countermovement jump height, 30 m sprint performance and maximum strength expressed relative to body mass, but non-significant correlations in absolute terms (r= |0.26| to |0.34|). In contrast, Comfort et al. (2014) reported comparable large to very large correlations for both absolute (r= |0.59| to |0.76|) and relative (r= |0.51| to |0.67|) strength measurements with speed strength performances.

Relative body mass, squats strength showed mostly moderate to large correlations with sprint performances (r= |0.44| to |0.67|), squat jump, and countermovement jump height (r= |0.35| to |0.69|), respectively (Boraczyński et al., 2020; Comfort et al., 2014; Keiner et al., 2014; McBride et al., 2009).

In a study conducted by Andersen et al. (2018) relative strength was calculated based on the estimated 1RM back squat divided by the athlete's body mass. Relative lower-body strength showed significant correlations with vertical jump ($r = 0.54$, $p < 0.05$).

The study by Wagner et al. (2023) was designed to analyze whether absolute and relative maximum strength measurements of the 1RM parallel squat correlate differently with different jump and sprint performances among a population of trained male youth soccer players. The data showed significant moderate to large correlations for relative strength and sprint and jump performances (r= |0.32| to |0.58|). However, only nonexistent to weak correlations (r= |0.16| to |0.30|) were found between absolute strength and sprint and jump performances.

The results of our study, along with those from the research conducted by few other authors, indicate several similarities. The findings by authors Wagner et al. (2023) are particularly noteworthy, as all r values representing the relative strength measures in relation to jump and sprint performances were significantly higher, as assessed by Fisher's Z, compared to those of absolute strength measures (p= 0.02 to 0.03). These outcomes, when combined with the results of our current study, suggest that superior speed strength performances are attributed to the athlete's capacity to exert greater force relative to their own body weight. Hence, it is reasonable to consider strength expressed relative to body mass as a better indicator for speed strength performance, particularly in short sprint and jump activities (Wagner et al., 2023). This inference aligns with prior literature demonstrating ground reaction forces during jumps to be 2 to 5 times the body weight (Bass et al., 2008; Hunter et al., 2005; Lafortune et al., 2000).

One of the objectives of our study was to examine whether absolute and relative maximum strength measurements of the 1RM and 1RM/BW back squat exhibit different correlations with various jump performances, such as countermovement jump (CMJ) and squat jump (SJ). We hypothesized that, while both absolute and relative strength are moderately to highly correlated with jump performances, the correlations of relative strength performances would be stronger.

Some factors contributing to the results of this study include technical differences and errors in the measurement and execution of absolute lower extremity strength (1RM), as well as technical differences and errors in the execution of Countermovement jumps (CMJ) and Squat jumps (SJ). Another factor could be the heterogeneous sample of participants from the student population; the students were not selected from a single sport, and their level of lower extremity strength varied.

Very similar findings have been established in the following studies. Technical disparities in measuring squats and squat jumps as maximum strength and speed strength tests could be a possible explanation for differences between the present study and previous studies. When determining a 1RM of the squat, a key limiting factor in many cases, especially in younger, less experienced athletes, seems to be trunk strength (Keiner et al., 2014).

In terms of evaluating the squat jump, similar difficulties could explain the lower correlations between the measurement and the observed values. Initiating a jump out of 90° knee flexion after a two second hold without momentum and pure concentric movement rarely belongs to the typical movement repertoire of a team sports athlete (Wagner et al., 2023). Therefore, it is reasonable to assume lower technical efficiency, resulting in limited force production and jumping height, especially when emphasizing on correct form without the utilization of momentum.

From the foregoing, this study has certain limitations in theoretical and practical usefulness. These limitations are reflected in the fact that the results of our research can mainly be applied to the population of students from sports faculties, thus they cannot be generalized and may not be fully applicable to elite selected athletes.

CONCLUSION

This study investigated the possibility of predicting vertical jump performance based on absolute and relative lower extremity strength. Prediction of vertical jump performance using absolute and relative lower extremity strength variables can be successfully established through the values of multiple correlations. Additionally, this study examined the relationships between absolute and relative lower extremity strength and vertical jump height. Based on the obtained Pearson's correlation coefficients, it was found that statistically significant relationships with moderately high correlations exist between absolute and relative lower extremity strength and vertical jump height.

We expect that this study will stimulate interest in future scientific research in the areas of lower extremity strength. The value of this research lies in the potential to emphasize the importance of increasing the level of absolute and relative lower extremity strength in classes at sports faculties, which will enable more efficient realization of the teaching process.

In the future, it would be interesting to conduct a similar study on sports faculty students who would be selected according to the sports they practice.

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Conflict of Interest

The authors do not have any conflicts of interest to disclose. All co-authors have reviewed and concurred with the manuscript's content, and no financial interests need to be reported.