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Original Article

Predicting the volleyball spike jump height by the force-time curve variables of countermovement and volleyball spike jump

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Abstract
Problem statement: Given the importance of achieving optimal performance in sports, monitoring, predicting, and enhancing sports performance is an important element for coaches and trainers. This study aimed to investigate the correlation between the force-time (F-T) curve variables of the concentric phase of the countermovement jump (CMJ) and the volleyball spike jump (VSJ) with the VSJ height in young female volleyball players. **Material and Methods:** Forty-two sub-elite young female volleyball players performed three VSJ and three CMJ in game-simulated circumstances on two 40cm×60cm Kistler force platforms (9290AD, Winterthur, Switzerland). **Results:** Pearson's product-moment correlations showed no significant correlation between the height of the VSJ and the F-T curve variables (r_{max} = .25) of the CMJ. The results of the multiple regression analysis showed no significant contribution of F-T variables of the CMJ in the prediction of the VSJ height (p = .835). Peak Force (r = .46, p = .002), Relative Peak Force (r = .31, p = .049), Peak Power (r = .56, p < .001), Relative Peak Power (r = .50, p = .001), and RSI_{mod} (r = .39, p = .010) of the VSJ had significant correlation with VSJ height. **Discussion**: The findings of this study support the importance of selecting an appropriate sport-specific jump test for assessment, monitoring, and predicting jump performance. **Conclusions:** Specifically, to the results of this study, coaches and trainers may use the F-T curve variables of the CMJ to assess the explosive strength of the lower limbs, but not for the prediction of VSJ height. In addition, measures of peak force and peak power during the VSJ, whether absolute or relative, were found to contribute significantly to the VSJ height.
Keywords: Volleyball, Rate of Force Development, Testing, Power, Stretch-Shortening Cycle

Introduction

Achieving maximum jump performance in volleyball spike jump (VSJ) is a frequent subject of sports analysis, whether kinetic (Slovák et al., 2021; Sarvestan et al., 2020a) or kinematic (Oliveira et al., 2020; Ikeda et al., 2018; Sarvestan et al., 2020b, Zahálka et al., 2017) because the height of the jump is seen as a key component, in having a higher success rate (Sarvestan et al., 2020b; Ziv & Lidor, 2010). Similar to a typical standing jump movement, such as a countermovement jump (CMJ) with arm swing, the VSJ is executed by both legs (McErlain-Naylor et al., 2014; Fuchs et al., 2019). Differing from standing vertical jumps, the VSJ movement is characterized by using arm swings during the last two or three counter-movement steps (Fuchs et al., 2021), while transferring the horizontal momentum of the body into the vertical acceleration before take-off (Wagner 2009). The stretch-shortening cycle (SSC), generating great power, rate of force development (RFD), and supporting an explosive push-off when adding the arm swing, have been described as key characteristics of VSJ performance (McLellan et al., 2011).

Given the importance of achieving optimal performance in sports, monitoring, and predicting sports performance is an important element for coaches and trainers (Hughes et al., 2019). Standardized tests should be used to determine jumping performance, which guarantee high validity and reliability and therefore, measurement accuracy (Reiman & Manske, 2009). As a typical standardized test for monitoring the explosive dynamics strength of the lower limbs and the height of the jump, the CMJ has been widely used in the literature (Haugen et al., 2020; Beato et al., 2021). Although not sport-specific, the CMJ is also used in testing to assess and improve volleyball jump performance (Zbinden-Foncea et al., 2018, Caroll et al., 2019; Sarvestan et al., 2020a; Ziv & Lidor, 2010). This may be due to the practical advantages of a standardized vertical jump such as the CMJ, which is easier to implement and interpret due to the great factorial validity and reliability of the jump (Sattler et al., 2012). Nevertheless, because of the VSJ movement's complexity, it may be more difficult to generalize the standardized performance assessments, such as CMJ (Fuchs et al., 2021). Therefore, less complex general jump types, such a CMJ, are used for training and testing (Ziv & Lidor, 2010; Beato et al., 2021).

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The course of a CMJ and VSJ can be recorded and evaluated similarly using the force-time (F-T) curve (Sarvestan et al., 2020a, Slovák et al, 2021). The F-T curve in these jumps is highly dependent on the patterning of the applied force over the execution time. Therefore, it can provide important variables that can affect or correlate with jump height (Laffaye et al., 2014, Slovák et al., 2021; Sarvestan et al., 2020a; Sarvestan et al., 2018; McLellan et al., 2011). Recently, many studies have dealt with the correlational analysis of F-T curve variables in the CMJ, to find the best contributor to jump height performance (McMahon et al., 2017; Marques et al., 2015; Laffaye et al., 2014; Sarvestan et al., 2019). The RFD is a logic-based variable of the F-T curve; however, the literature is still inconsistent as to whether the course of applied force during the take-off has a significant effect on the jump height, during the jumping performance (McLellan et al., 2011; Marques et al., 2015; Sarvestan et al., 2019; Claudino et al., 2017; Slovák et al., 2021). The peak power (PP), as a product of velocity and ground reaction force, also seems to be a significant kinetic contributor to the jump height (Slovák et al., 2021; McBride et al., 2010). The modified reactive strength index (RSI_{mod}) is a globally valid variable that can assess the efficiency of the SSC or maximal explosive power during the jumping performance and thus, could help to predict jumping performance in similar jumping tasks (Suchomel et al., 2015; Sarvestan et al., 2020a). However, sport-specific jump performance (due to different jump patterning) may require different analysis to monitor contributive parameters to higher jump heights.

Although the above literature provides initial information about the significant contributors to jump performance (based on the F-T curve variables of the CMJ), further precise investigations are needed. This would expand the current knowledge of the possibility of the CMJ application as a tool for the evaluation and prediction of sport-specific jump performances, such as VSJ. Verification of correlational variables could help broaden the relationship between the VSJ and the CMJ, thus helping coaches and athletes understand the relationship between the VSJ and the CMJ, as well as assess the choice of an appropriate jump performance test. Therefore, this study aimed to investigate the correlation between the F-T curve variables of the CMJ and the VSJ with the height of the VSJ in young female volleyball players. It was hypothesized that measures of RFD, power, and RSI_{mod} of the CMJ and VSJ would contribute to the VSJ height.

Materials and Methods

1.1. Participants

Forty-two sub-elite young female volleyball players (age: 15.92±2.20 years, height: 170.49±5.82 cm, Weight: 59.29±6.35 kg, BMI: 20.67±2.32, experience: 6.09±2.26 years) voluntarily participated in this study. The participants included 10 setters, 15 middle blockers, and 17 wing spikers. A priori power analysis indicated that with the power of (1 - β) 0.85 and α of 0.05, a total sample size of 42 is sufficient for a bivariate correlation analysis. Of the inclusion criteria, the players were required to participate in a volleyball training routine with a minimum frequency of three times a week for three years. Participants did not report a history of muscle or ligament rupture or surgery, joint laxation, or bone fracture within the 12 months before measurement (Gribble et al., 2013). During the measurement, no acute pain was disclosed. The entire measurement protocol, aims, measurement-related risks of injury and benefits, as well as the objectives and justification of the research, were comprehensively explained to individuals. This study was ethically approved by the Palacky University's Institutional Review Board (ethics code of 79/2018) and all participants and their parents/coaches (in case they were below 18 years old) signed the written informed consent, which meets the ethical standards of the Declaration of Helsinki.

1.2. Instrument and procedure

After a 10-minute general and a 10-minute volleyball-specific warm-up, participants randomly performed three volleyball spike jumps (VSJ) and three CMJs (using arm swings - to a self-selected depth) on two 40cm×60cm Kistler force platforms (9290AD, Winterthur, Switzerland) with the sampling frequency of 1000Hz (McMahon et al., 2017; Sarvestan et al., 2020a). The authentication of both VSJs and CMJs was checked and approved by expert trainers. Since players use arm swings to achieve higher jump heights in VSJs, we employed the CMJs with arm swings to counterbalance the impacts of arm swings in both conditions (Sarvestan et al., 2020a). From 3-dimensional sampled data, we exported the vertical F-T data set for further analysis.

1.3. Data Analysis

Before data analysis, both CMJ and VSJ were trimmed from the start of the unweighting phase to the takeoff moment (Sarvestan et al., 2018). The impulse values were calculated using trapezoidal integration of the F-T curve throughout both jumps (Sole et al., 2018). Applying Newton's second law of motion, the instantaneous acceleration of the center of mass (COM) was calculated; thereafter, the instantaneous velocity and displacement of the COM were calculated using the first and second integration of the acceleration time series data (McMahon et al., 2017). By multiplication of the force and velocity values, the power measures at each data point were calculated. Vertical jump heights for both VSJ and CMJ were calculated using the take-off moment velocity (Moir, 2008).

Adopting the first derivatives of the F-T curve, the maximum rate of force development (RFD) was calculated (McLellan et al., 2011). The modified reactive strength index (RSI_{mod}) values were calculated by dividing the jump heights by the time to take-off (movement time) (Ebben & Petushek, 2010). Data normalization was conducted by dividing the absolute values by body mass. The average measures of three VSJs and three CMJs were then calculated for further statistical analysis. The analyzed F-T curve variables were Jump Execution Time (JET), Time to Relative Peak Force (TtRPF), Peak Force (PF), Relative Peak Force (RPF), Peak Rate of Force Development (PRFD), Average Rate of Force Development (RFD_{mean}), Peak Power (PP), Relative Peak Power (RPP) and Modified Reactive Strength Index (RSI_{mod}).

1.4. Statistical Analysis

The Shapiro-Wilk statistical test was used to check the normality of variable distribution. The equality of variance was assessed using the Levene test. Employing the interclass correlation coefficient (ICC, Model: Two-way random effects, Type: Singletrial, Definition: Absolute agreement), the within session reliability of the data (for both jumps) was checked (Koo & Li, 2016). The ICC values were interpreted as <0.4 poor; 0.4–0.7 fair; 0.7–0.9 good; and>0.9 excellent. To determine the relationship between the F-T curve variables of CMJ and VSJ with VSJ height, Pearson's product-moment correlations were employed. For the regression analysis, all F-T curve variables of VSJ and CMJ were assessed as separate models, and the coefficient of determination (R^2) was adopted for the interpretation of the relationships between the variables (Thomas, Nelson, & Silverman, 2015). The significance level was set at α = 0.05. Statistical analysis was performed using MATLAB (v. 2020a, MathWorks, Inc., Natick, MA, USA).

Results

A relatively good within-session reliability between F-T curve variables of CMJs (minimum ICC = .89) and VSJs (minimum ICC = .92) was observed. Table 1 demonstrates the descriptive measures of the F-T curve variables in VSJ and CMJ and their correlations with VSJ height. PF (r = .46, *p* = .002), RPF (r = .31, *p* = .049), PP (r = .56, *p* < .001), RPP (r = .50, *p* = .001), and RSI_{mod} (r = .39, *p* = .010) of the VSJ had significant correlation with VSJ height. No significant correlations were observed between the movement timing and RFD values of the VSJ with the VSJ height. No F-T curve variables of the CMJ significantly correlated with VSJ height. Although no significant correlation was found between the timing of both VSJ and CMJ with VSJ height; in VSJ, participants reached their peak relative forces sooner than in CMJ, as shown in Figure 1.

Table 1. Descriptive measures of VSJ and CMJ F-T curve variables and their correlation with VSJ height.

	VSJ			CMJ		
Variables	Mean (SD)	r	Sig. (2-tailed)	Mean (SD)	r	Sig. (2-tailed)
JET (s)	.44 (.035)	-.23	.143	.81 (.029)	-.05	.741
TtRPF (%)	65(6)	.12	.475	83(4)	.24	.121
PF(N)	2006 (139)	.46**	**.002**	1461 (237)	.25	.112
RPF ($N.Kg^{-1}$)	33.73 (5.29)	.31*	**.047**	24.59 (2.80)	.10	.517
PRFD ($N.s^{-1}$)	14515 (935)	.19	.219	8729 (650)	.22	.163
RDF_{mean} ($N.s^{-1}$)	9024 (678)	.24	.121	5421 (464)	.23	.134
PP (W)	7989 (1338)	.56**	**.000**	3804 (844)	.24	.121
RPP ($W.Kg^{-1}$)	134.89 (18.68)	.50**	**.001**	64.45 (10.58)	.11	.492
RSI_{mod}	2.65 (.239)	.39*	**.010**	.47 (.013)	.06	.724

JET: Jump Execution Time, TtRPF: Time to Relative Peak Force, PF: Peak Force, RPF: Relative Peak Force, PRFD: Peak Rate of Force Development, RFD_{mean}: Average Rate of Force Development, PP: Peak Power, RPP: Relative Peak Power, RSI_{mod}: Modified Reactive Strength Index.
* significant at p<0.05 ** significant at p<0.01

The results of multiple regression analysis indicated that the F-T variables of the VSJ had a significant contribution (*p* = .017, R^2 = .367) in the prediction of VSJ height. RFD (*p* = .032), PP (*p* = .039), and RPP (*p* = .042) had the greatest contribution to the prediction of VSJ height (Table 2). No significant contribution (*p* = .835, R^2 = .162) was observed by the F-T variables of the CMJ in the prediction of the VSJ height.

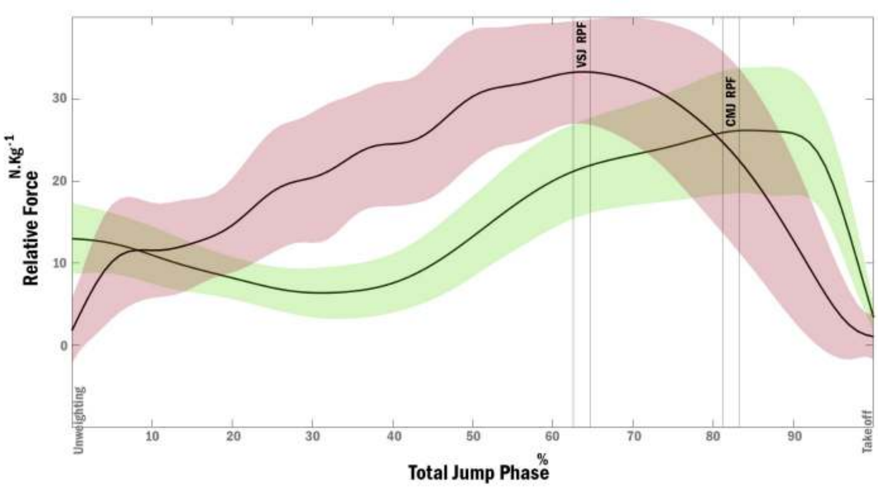

Figure 1. The time series of the F-T curve in CMJ (light green) and VSJ (Red) performances.

Table 2. Multiple regression analysis between F-T curve variables of VSJ and CMJ with VSJ Heights.

Independent variables	VSJ Height				
	Standardized β coefficient	β significance	R^2	Adjusted R^2	Model significance
Model 1 (VSJ Variables)			.367	.240	**.017**
JET (s)	.125	.376			
TtRPF (%)	.221	.247			
PF(N)	-.088	.602			
RPF ($N.Kg^{-1}$)	-.037	.850			
PRFD ($N.s^{-1}$)	-.141	.610			
RDF_{mean} ($N.s^{-1}$)	.473	**.032**			
PP (W)	.439	**.039**			
RPP ($W.Kg^{-1}$)	.422	**.042**			
RSI_{mod}	.211	.285			
Model 2 (CMJ Variables)			.162	-.035	.835
JET (s)	.044	.792			
TtRPF (%)	.029	.832			
PF(N)	.209	.738			
RPF ($N.Kg^{-1}$)	.203	.585			
PRFD ($N.s^{-1}$)	-.026	.936			
RDF_{mean} ($N.s^{-1}$)	.075	.806			
PP (W)	.227	.798			
RPP ($W.Kg^{-1}$)	-.724	.271			
RSI_{mod}	.188	.681			

R^2 = coefficient of determination.

Discussion

The main objective of this study was to investigate the relationship between F-T curve variables of the CMJ and VSJ with VSJ height in young female volleyball players. The findings indicate that the F-T curve variables of the CMJ are not good predictors of the VSJ height in young females. The correlation analyses of the F-T curve variables of the VSJ investigated the Peak Force, Relative Peak Force, Peak Power, Relative Peak Power, and RSI_{mod} as significant contributors to predicting the VSJ height.

In the study by Fuchs et al., the height of the VSJ was well correlated with the height of the squat jump (r = .88), CMJ without arm swing (r = .88), and CMJ (r = .82) (Fuchs et al., 2021). This suggests a strong relationship between general jump performance and sport-specific VSJ performance. Nevertheless, the current kinetic analysis has not shown any significant relationship between the F-T curve variables of the CMJ and the height of the VSJ. The results could be logical because the course of the F-T curve in both CMJ and VSJ differs concerning the nature of the jump (Figure 1). The CMJ, in particular, is executed in a more static condition, compared to the VSJ. Hence, during the CMJ, athletes could be limited in the static standing position due to the standardization of the CMJ test (Fuchs et al., 2021). Therefore, athletes could not apply their specific jumping potential, which may be more influenced by the VSJ technique (Fuchs et al., 2019; Wagner, 2009).

On the other hand, similarly in the CMJ and VSJ performance, athletes start with a prior countermovement, which is a prerequisite for the SCC (Watkins, 2014). Although in both, VSJ and CMJ participants used a countermovement method, VSJ benefits more from the approach phase velocities, which may help in better activation of the SSC (Watkins, 2014). This could be the main reason for reaching the PF values sooner in VSJ, as the activation of SSC was more powerful and shorter. It should also be considered that although the F-T curves (Figure 1) were normalized, the real PF values in VSJ were reached sooner as the VSJ execution time was half of the CMJ. This shorter JET in VSJ could be the main reason for higher produced force, RFD, power, and RSI_{mod} measures. In addition, this may also support the consideration of limited static conditions during the CMJ.

Currently, one study is known that has sought to elucidate the relationship between the F-T variables of the CMJ and the height of the VSJ (Sarvestan et al., 2020a). The study by Sarvestan et al. (2020a) identified RSI_{mod} (r = .56), measures of the RFD (r = .75-76), and concentric net impulse (r = .61) as the main contributors to predicting the VSJ height. Multiple regression analysis between the above variables determined the significant model of prediction of the VSJ height (< .001, r = .71). Although the study by Sarvestan et al. (2020a) appropriately compared the dependences of F-T variables of the CMJ with the jump height in a game-like situation, these results are interpreted with caution with respect to small sample size (n = 13). Furthermore, the current study compared the game-simulated VSJ height with the maximal jump effort. With more closed testing conditions in the current study (not affected by the quality of the set or the impact of the ball in a game-like jump). The results of the jump height of VSJ could be more accurate and thus could interpret a more valid result. Additionally, in the current study, compared to Sarvestan et al. (2020a), the height of the VSJ was analyzed using a kinetic platform (compared to the kinematic method). Therefore, all variables were measured using the same approach. Finally, while the study by Sarvestan et al. (2020a) investigated the performance of young male players, this study provides information on sports training and testing for young females.

Regarding the VSJ variables, the study by Slovák et al. (2022) found that the Peak Force, whether relative or absolute, was not significantly related to the height of the VSJ in young females. Nevertheless, the present study investigated significant correlations between Peak Force and Relative Peak Force with the height of the VSJ. Therefore, the role of the Peak Force during transferring the horizontal momentum of the body into the vertical acceleration before take-off needs to be still further examined. However, a significant correlation in the current study between the Relative Peak Power and RSI_{mod} with the VSJ height is in line with Slovák et al. (2022). Although these correlations were significant in the current study, the prediction rate of the model was only (37%) (Table 2). Therefore, these results are interpreted with caution and provide only additional overview of the relationship between the variables analyzed. The analysis of F-T curve variables in sport-specific jump performance is unique, these results could be a cornerstone for future research and could also help coaches in designing sport-specific jump training programs.

The essence of the SCC is faster power generation, which is necessary for explosive dynamics movements such as volleyball VSJ (Watkins, 2014; Ziv & Lidor, 2010; Soundara & Pushparajan; 2010). Therefore, kinetic analyzes of the F-T curve variables of the CMJ provide useful information about the quality of SSC (Barker et al., 2018, McMahon et al., 2017; Sarvestan et al., 2018, Slovák et al., 2022), which is an important aspect of the VSJ (Sheppard et al., 2008). However, due to the different characteristics of jumps (absence of approach speed and approach technique in CMJ), the relationship between the F-T curve variables of VSJ and CMJ with VSJ height may be different. Therefore, by the results of this study, coaches and trainers could use the F-T curve variables of the CMJ to assess the explosive strength of the lower limbs, but not for the prediction of sport-specific jump heights. The results of the current study could expand the knowledge in predicting jump performance in sports-specific jumps, especially for coaches or trainers who have limited tools to evaluate their athletes' performance.

This study has several limitations. In both, VSJ and CMJ, participants were limited to jumping on the force plate, which could influence maximal jump performance. Nevertheless, all participants were instructed to perform the highest possible jumps. Moreover, the chosen kinetic analysis does not provide information about the quality and scope of the arm swing during both the VSJ and CMJ. However, participants were asked to take advantage of their maximum arm swing benefits when performing both, the VSJ and the CMJ.

Conclusion

The results of the study suggest that measures of the Peak Force and Peak Power during the VSJ, whether absolute or relative, of the concentric phase of the VSJ may predict the height of the VSJ in young female players. Furthermore, the significant correlation found between the Peak Force and the Relative Peak Force with the VSJ height supports the association between the amount of force applied during the concentric take-off phase and the height of the VSJ. On the other hand, no significant correlations between the F-T curve variables of the concentric phase of the CMJ and the height of the VSJ was found. This could be explained by the limited conditions during the CMJ performance, where participants could not execute a sport-specific course of force application during the jump. The findings of this study support the importance of selecting an appropriate sport-specific jump test for assessment, monitoring, and predicting jump performance. In other words, coaches and trainers are not recommended to evaluate and predict the VSJ height based on the F-T curve variables of the concentric phase of the CMJ. Overall, the results of this study support a significant difference in the kinetic course of both jumps and, therefore, it is recommended to use kinetic variables of the VSJ to predict the height of the VSJ. Future analyzes could address the relationship between F-T curve variables and particular jump performance across different sport-specific jumps.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Ethical approval

The Institutional Review Board of Faculty of Physical Culture, Palacky University Olomouc, ethically approved this study (ethics code of 79/2018).

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