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Research Paper

A Correlation Study between Body Mass Index and Force-Time Curve Variables in Jumping and Landing of Junior Volleyball Players

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Abstract

The study of force-time curve variables, considering the demographic characteristics, represents an exclusive finding of vertical jumping performance among elite youth volleyball players. Therefore, the aim of the present study was to determine the correlation between BMI and force-time curve variables in jumping and landing of junior volleyball players. Twenty-one junior male volleyball players were asked to perform maximal jumps. The height and body mass of each player were considered as the body mass index. Also force-time curve variables of jumping and landing were calculated directly from the force plate output. Pearson's moment coefficient was employed to investigate the correlation between body mass index with force – time variables during jumping and landing ($p < 0.05$). The results showed that there were significant correlations between BMI with power peak concentric ($r = 0.49$, $p < 0.03$), average power concentric ($r = 0.53$, $p < 0.024$), maximum landing force ($r = 0.52$, $p < 0.25$), and time to peak landing force ($r = -0.47$, $p < 0.04$) Because BMI have the correlation of mentioned variables, our findings confirmed the importance of average and relative peak power of the concentric phase to attain higher jumps coaches and athletes can focus on them to control athletes' jump and landing performance.

Keywords: BMI, Jumping, Landing, Force-Time Curve, Volleyball Players

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Introduction

Jumping and landing is one of the most common fundamental motor skills, and, in various sports, the capacity to jump higher than an opponent can be advantageous in competition. Therefore, improving the vertical jumping ability of athletes can be an important challenge for coaches, as well as strength and conditioning professionals, who often use this skill to assess athletic performance and physical conditioning (Salles, Baltzopoulos, & Rittweger, 2011). On the other hand, jumping and landing skill has always been one of the most common mechanisms of lower limb injuries among athletes (Wikstrom, Tillman, Schenker, & Borsa, 2008). In this type of activity, researchers have mentioned ground reaction force and higher loading rate as one of the biomechanical risk factors for lower limb injury (Policastro, Andrea, Fadi, & Accardo, 2020; Sarvestan, Cheraghi, Sebyani, Shirzad, & Svoboda, 2018). Because the maximum vertical jump is often used for assessing muscular strength and power of lower limbs (Policastro et al., 2020), extensive research has been conducted to determine the kinetic and kinematic parameters of jump and landing that must be improved to increase vertical jump height (Hale, Kollock, Pace, & Sanders, 2019; Sánchez-Sixto, Harrison, & Floría, 2018).

In volleyball, due to the presence of many jumping and landing movements, along with a large amount of ground reaction force, various injuries about 77%, including lateral wrist sprain, have been reported (Shaw, Gribble, & Frye, 2008). Because jumping movements such as spike or defense on the net in volleyball do not only involve jumping, but also the subsequent landing movement, this step requires the distribution of the movement force produced in jumping and the use of various movement patterns to absorb body energy during landing (Tillman et al., 2002). On the other hand, it should be noted that the characteristics of physical dimensions in athletes are among the primary factors that can affect their movements, skills and daily life, hence paying attention to the effects of these factors during physical and motor evaluations is of particular importance (Sarvestan et al., 2018; Tillman et al., 2002). Body mass index (BMI) is a statistical measure to compare a person's weight and height. In fact, this index does not measure the rate of obesity, but is a suitable tool to estimate a person's weight health according to their height (Prentice & Jebb, 2001). Since BMI can be mechanically effective in controlling the balance and variables of the force-time curve (Sarvestan et al., 2018), any change in it may change the characteristics of a volleyball player's force-time curve during the jump and landing (Rojano-Ortega, Berral-Aguilar, & Berral-De La Rosa, 2021; Sarvestan et al., 2018). In general, landing leads to the production of ground reaction force and it has been proven that sometimes this amount of force reaches five times the person's body weight, thus increasing or decreasing the BMI, which is part of the accompanying and intervening parameters in any athlete, can affect the kinetic and kinematic variables of the athlete's jump and landing (Salles et al., 2011). Force-time curve variables are used to evaluate neuromuscular and biomechanical properties related to lower limb dynamics (Claudino et al., 2017). Therefore, the exclusive study of force-time curve variables in jumping and landing by emphasizing and paying attention to demographic parameters, body type and BMI, can help us identify the factors affecting jumping (Cormie, Mcguigan, & Newton, 2010; Laffaye, Wagner, & Tombleson, 2014; Riggs & Sheppard, 2009). On the other hand, the study of force-time curve variables in different stages of jumping, considering the demographic characteristics, is a good indicator for an exclusive and comprehensive study of vertical jumping performance among elite youth volleyball players (Sarvestan et al., 2018).

Vertical jumping is an integral part of fitness training in most sports such as volleyball and basketball, and body mass index has a direct effect on the height of the jump and the amount of force applied to the lower limbs (Duthie, Young, & Aitken, 2002; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Since these two factors can functionally and dynamically affect volleyball players in jumping and landing, it is very important to find variables that affect the final height and the amount of force applied to the lower limb. Based on the study conducted by Palao et al., (2008) about height, weight, body mass index, and age in beach volleyball players in relation to level and position, with regard to weight and BMI, the higher the level, the larger the value in volleyball performance. Indeed, the players at a higher level presented higher values of age, height, weight, and BMI. With regard to role, the blocking specialists were taller than the defense specialists. The pairs that share the blocking and defense responsibilities have intermediate values (Palao, Gutiérrez, & Frideres, 2008). Further, Nikolaidis (2013) revealed that body mass index and body fat percentage are associated with decreased physical fitness in adolescent and adult female volleyball players (Pantelis Theo Nikolaidis, 2013). On the other hand, Riggs and Shepherd (2009) and Jidovtseff et al. (2014), as well as also some other studies (Hue et al., 2007; Jidovtseff et al., 2014; Laffaye et al., 2014; Sarvestan et al., 2018; Wikstrom et al., 2008) suggested that there are strong relationships between kinetic-temporal variables of block jumping and landing. However, due to the paucity of studies concerning relationships between athletes' demographic characteristics with jumping and landing performance, more understanding is needed on how BMI can affect athlete force-time curve variables and subsequent performance during this task. In other words, as no similar research has been found to determine the extent of changes in the force-time curve during jumping and landing with increasing body mass index, this relationship between BMI and force-time curve variables can be an important predictor of possible injuries (Rojano-Ortega et al., 2021). Therefore, the aim of the present study was to determine the correlation between BMI and force-time curve variables in jumping and landing of junior volleyball players.

Methods

Participants

Twenty-one junior male volleyball players participated in this study (age: 17.71±0.90 yrs., weight: 768.28±59.68 N, height: 195.66±2.93 cm (mean ± SD). The study's subjects participated continuously in volleyball training sessions weekly. The exclusion criteria were considered if they had any musculoskeletal or neurological deficit as well as any injury history that could influence jumping and landing tasks. Written informed consent was obtained prior to testing. The study followed the Declaration of Helsinki's recommendations. Additionally, all the processors of study were confirmed by the Research Ethics Committee of Sport Sciences Research Institute (code: IR.SSRI.REC.1151).
Testing was performed in the Olympic Laboratory and under supervision of the volleyball federation of Islamic Republic of Iran.

Study Design

The athletic task tested in this study was block jump skill which typically is considered as a countermovement jump (CMJ). This technique is performed with the contribution of the stretch-shortening cycle. The subject starts from a ready position with the hands in front of his chest and fingers extended. CMJ begins with a preliminary downward movement by flexing at the knees and hips (eccentric phase) and then the knees and hips are immediately extended again to jump vertically (concentric phase) at the least time while the hands moving upward and totally extended above the head (Fatahi, Yousefian Molla, & Ameli, 2020; Fatahi, Yousefian Molla, Tabatabai Ghomsheh, & Ameli, 2021). At the beginning of the test, the warm-up protocol was performed individually for 15 minutes according to official conditions of the volleyball training sessions or games. The athletes were encouraged to jump "as high as possible". For each subject, three to five times practice was allowed to be more familiar with the appropriate procedure of the test. For minimizing the coach role, no verbal instructions were described for players. Data collection started with the calibration of the force platform system (Kistler® force platform with sampling rate of 1000 Hz). Participants were asked to perform three maximal jumps and between each trial, a one-minute rest was considered. Best of the three was considered for further analysis. The height and body mass of each player were considered as the body mass index according to the equation (1) (Prentice & Jebb, 2001). Data of Kinetics-temporal variables from force-time curve variables were calculated for the best jump trial and were exported by processes in MATLAB programs software (Math Works Inc., Cambridge, MA, USA).

$$BMI = \frac{Body\ Mass\ (kg)}{Height^2\ (m^2)} \qquad Equation\ (1)$$

Data Analysis

In order to estimate BMI, participant's stand on a force plate without any movement and the amount of F_z was considered as their weight (N). To determine the height of each subject, a tape meter was used. In this way, every subject stands in front of the tape meter, then his height was recorded (cm).

To calculate the instantaneous velocity of center of mass (COM), first, instantaneous acceleration of center of mass was calculated by dividing vertical ground reaction force minus weight of the participant to his mass and then integrating with respect to time by trapezoid method (Sarvestan et al., 2018).

Different phases of jumping were calculated as below (Figure 1):

- Initiation Phase (IP) (ms): when the instantaneous velocity of COM started to decrease from zero to its lowest Value.
- Eccentric Phase (ECC) (ms): started immediately after the initiation phase and lasted until the instantaneous velocity of COM became equal to zero.
- Concentric Phase (CON) (ms): started when the instantaneous velocity of COM became positive, and lasted until the participant left the force platform.

Following these stages, power in vertical direction for each frame was calculated according to equation (3) (Jidovtseff et al., 2014):

$$P_i = F_i \times V_i \qquad \text{Equation 3.}$$

Moreover, force-time curve variables of jump were divided into following subsets during eccentric and concentric according to the similar investigation (Sarvestan et al., 2018) (Figure 1):

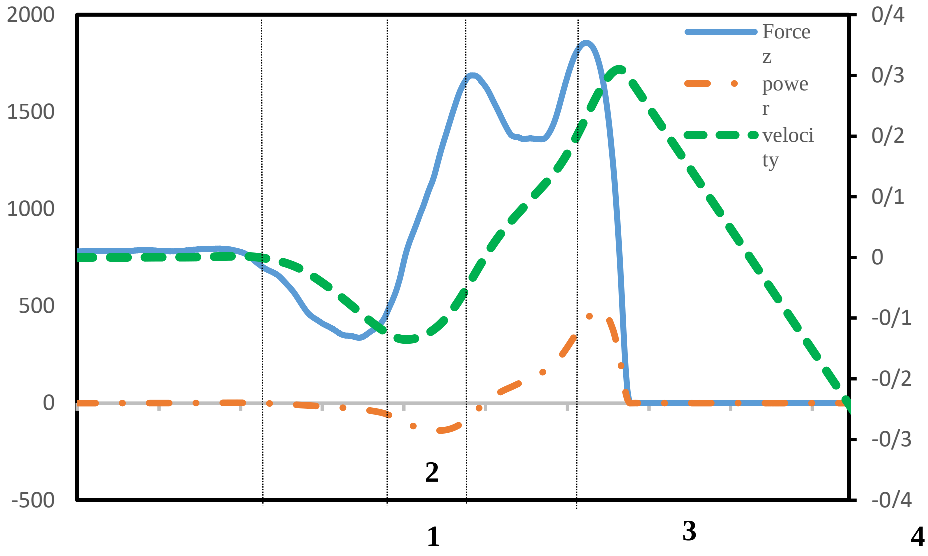


Figure 1. Jumping Graph. Vertical force (solid blue line), Instantaneous Velocity (dot green line) and Power (dot orange line) with respect to Time from the beginning of Block Jump till impact of landing. Phases are separated according to the Velocity curve: 1). Initiation phase, 2). Eccentric phase, 3). Concentric phase, 4). Airborne phase

- Time Initiation (T_{I}) (ms): Time duration in initiation phase.
- Eccentric Time (T_{ECC}) (ms): Time duration in eccentric phase.
- Concentric Time (T_{CON}) (ms): Time duration in concentric phase.
- Maximum Eccentric Force ($F_{ECC\ MAX}$) (N/kg): Maximum force calculated from eccentric phase normalized to body weight.
- Maximum Concentric Force ($F_{CON\ MAX}$) (N/kg): Maximum force calculated from concentric phase normalized to body weight.
- Average Power Concentric (A Power$_{CON}$) (W/kg): Average of power calculated during concentric phase normalized to body weight.
- Average Power Eccentric (A Power$_{ECC}$) (W/kg): Average of power during eccentric phase normalized to body weight
- Peak Power Concentric (P Power$_{CON}$) (W/kg): Peak value of calculated power during concentric phase normalized to body weight
- Peak Power Eccentric (P Power$_{ECC}$) (W/kg): Peak value of calculated power during eccentric phase normalized to body weight
- Time to Peak Power Concentric (TPPower$_{CON}$) (ms): Time elapsed from the beginning of concentric phase until peak of calculated power
- Time Peak Power Eccentric (TPPower$_{ECC}$) (ms): Time elapsed from the beginning of eccentric phase until peak of calculated power

- RFD Maximum Concentric (RFD $_{\text{MAX CON}}$) (N/ms): Calculated by dividing peak force of concentric phase to time elapsed between beginning of concentric phase until peak force normalized to body mass.
- RFD Maximum Eccentric (RFD $_{\text{MAX ECC}}$) (N/ms): Peak of eccentric force dividing time elapsed between beginning of eccentric phase until peak force, normalized to body mass.
- Average RFD Concentric (ARFD $_{\text{CON}}$) (N/kg/s): Average of RFD calculated between each consecutive frame according to equation 2 in concentric phase normalized to body mass
- Average RFD Eccentric (ARFD $_{\text{ECC}}$) (N/kg/s): Average of RFD calculated between each consecutive frame in concentric phase normalized to body mass
- Peak RFD Concentric (PRFD $_{\text{CON}}$) (N/ms): Peak value of force dividing by elapsed time from the beginning of concentric phase until the peak force normalized to body mass.
- Peak RFD Eccentric (PRFD $_{\text{ECC}}$) (N/ms): Peak value of force dividing by elapsed time from the beginning of eccentric phase until the peak force normalized to body mass.

Then, dforce-time curve variables of landing were divided into the following subsets during to the similar investigation (Sarvestan et al., 2018) (Figure 2):

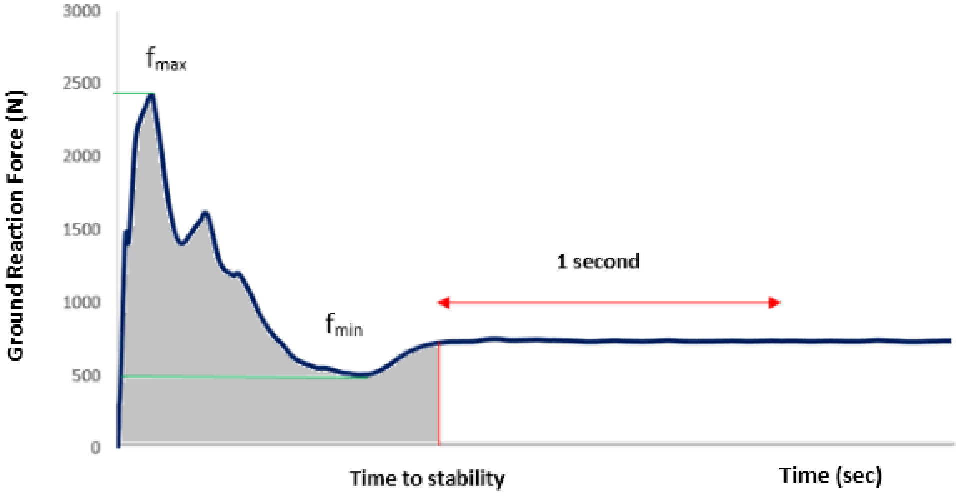


Figure 2- Landing Graph (the grey area represents Impulse).

- Time to Stabilization (TS) (s): The interval between contact time and the instance as the measured force will remain constant at least for one second on the force plate.

- Impulse (I) (N.S): The area below the force – time curve of landing from contact to stability.
- Time of Maximum to Minimum Force: ($TF_{max-min}$ L) (s): The interval between time of the maximum and minimum peak of force in landing.
- Maximum Landing Force (F_{maxL}) (N/kg): The highest peak of force derived from force plate output in landing phase normalized to the body weight.
- Minimum Landing Force (F_{minL}) (N/kg): The lowest peak of force derived from force plate output in landing phase normalized to the body weight.
- Maximum Loading Rate (LR_{max}) (BW/S): The ratio of the body weight normalized maximum landing force to time from contact to maximum force.
- Time to Peak Force Landing (TPF) (s): The interval between contact and time of maximum force.
- Maximum to Minimum Loading Rate ($LR_{MAX-MIN}$) (BW/S): Difference between maximum and minimum force of landing divided to interval time between two peaks
- Flight Time (FT) (s): Time from leaving the force plate till contact.

Statistical analysis

To check the normality of variable distribution, Shapiro-Wilk' test was performed. Statistical descriptive means and standard deviation were estimated. Pearson's moment coefficient was employed to investigate the correlation between body mass index with force – time variables during jumping and landing. Statistical significance was set at $p < 0.05$.

Results

Results of the Shapiro-Wilk test showed that the data distribution was normal in all variables of the study. Descriptive measures of kinetics and temporal variables during jumping and landing are shown in Table 1.

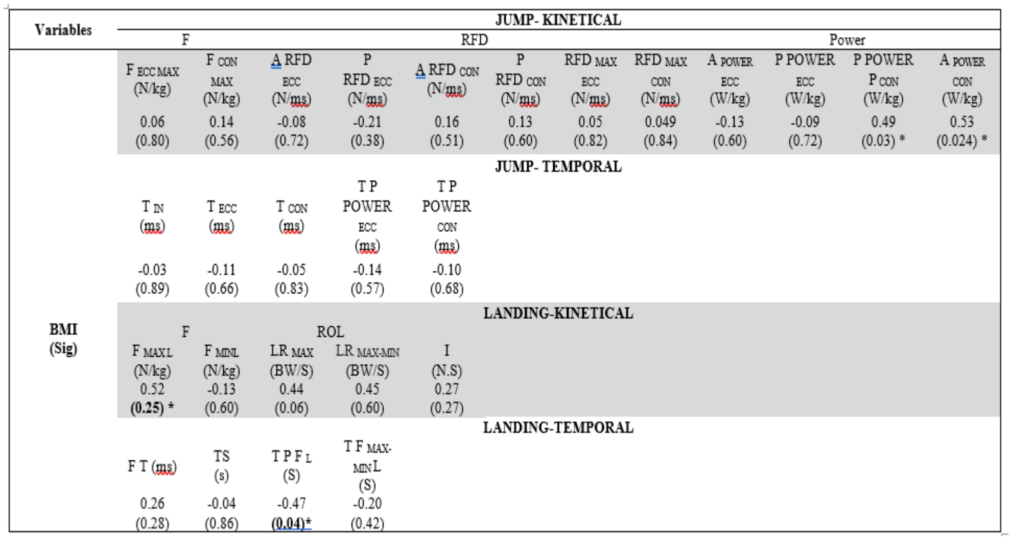
Table 1- Descriptive measures of kinetics and temporal variables during jumping and landing

Variables	Mean ± SD	Variables	Mean ± SD
BMI (kg/m^{2})	20.20± 1.46	T P POWER $_{\text{CON}}$ (ms)	319.44 ± 55.98
T $_{\text{I}}$ (ms)	361.88 ± 112.87	A POWER $_{\text{ECC}}$ (W/kg)	-8.12 ± 3.17
T $_{\text{ECC}}$ (ms)	286.00 ± 92.30	A POWER $_{\text{CON}}$ (W/kg)	25.63± 6.68
T $_{\text{CON}}$ (ms)	344.16 ±80.07	RFD $_{\text{MAX ECC}}$ (N/ms)	75.90 ± 38.07
F T (ms)	585.88 ± 95.50	RFD $_{\text{MAX CON}}$ (N/ms)	76.64 ± 20.13
A RFD $_{\text{ECC}}$ (N/ms)	38.44 ± 18.61	TS (s)	1.85 ±0.93
P RFD $_{\text{ECC}}$ (N/ms)	6.80 ± 2.41	F $_{\text{MAX L}}$ (N/kg)	3.37 ± 0.88
A RFD $_{\text{CON}}$ (N/ms)	-27.16 ± 9.37	T P F $_{\text{L}}$ (S)	0.08 ± 0.03
P RFD $_{\text{CON}}$ (N/ms)	5.83 ± 2.01	LR $_{\text{MAX}}$ (BW/S)	46.91 ± 24.27
F $_{\text{ECC MAX}}$ (N/kg)	1.89 ± 0.25	F $_{\text{MIN LANDING}}$ (N/kg)	0.63 ± 0.13
F $_{\text{CON MAX}}$ (N/kg)	2.17 ± 0.16	T F $_{\text{MAX-MIN}}$ L (s)	0.60± 0.15
P POWER $_{\text{ECC}}$ (W/kg)	-10.23.68 ±4.31	LR $_{\text{MAX-MIN}}$ (BW/S)	4.96 ± 2.25
P POWER $_{\text{CON}}$ (W/kg)	52.31 ±13.68	I (N.S)	0.36 ± 0.03
T P POWER $_{\text{ECC}}$ (ms)	96.16 ± 54.88		

*Time Initiation (T $_{\text{I}}$); Eccentric Time (T $_{\text{ECC}}$); Concentric Time (T $_{\text{CON}}$); Maximum Eccentric Force (F$_{\text{ECC MAX}}$) (N/kg); Maximum Concentric Force (F$_{\text{CON MAX}}$); Average Power Concentric (A Power $_{\text{CON}}$); Average Power Eccentric (A Power $_{\text{ECC}}$); Peak Power Concentric (P Power $_{\text{CON}}$); Peak Power Concentric (T P Power $_{\text{CON}}$); Time Peak Power Eccentric (T P Power $_{\text{ECC}}$); RFD Maximum Concentric (RFD$_{\text{MAXCON}}$); RFD Maximum Eccentric (RFD$_{\text{MAXECC}}$); Average RFD Concentric (ARFD$_{\text{CON}}$); Average RFD Eccentric (ARFD$_{\text{ECC}}$); Peak RFD Concentric (PRFD$_{\text{CON}}$); Peak RFD Eccentric (PRFD$_{\text{ECC}}$); Time to Stabilization (TS); Impulse (I); Time of Maximum to Minimum Force: (T F$_{\text{max-min}}$ L); Maximum Landing Force (F$_{\text{max L}}$); Minimum Landing Force (F$_{\text{min L}}$); Maximum Loading Rate (L R$_{\text{max}}$); Time to Peak Force Landing (TPF); Maximum to Minimum Loading Rate (LR $_{\text{MAX-MIN}}$); Flight Time (FT)

Table 2 demonstrates the correlation coefficients between principal variables of study. As it can be observed, there are significant correlations between BMI with POWER P $_{\text{CON}}$, A POWER $_{\text{CON}}$, F $_{\text{MAX}}$ L, and T P F $_{\text{L}}$.

Table 2- The correlation between BMI and Kinetic-Temporal in Jumping and Landing of Volleyball Players (upper numbers represent the correlation coefficient (r) and lower numbers in parenthesis represent the p- value)



Variables	JUMP- KINETICAL											
	F		RFD						Power			
	$F_{ECC\,MAX}$ (N/kg)	$F_{CON\,MAX}$ (N/kg)	A RFD_{ECC} (N/ms)	P RFD_{ECC} (N/ms)	A RFD_{CON} (N/ms)	P RFD_{CON} (N/ms)	$RFD_{MAX\,ECC}$ (N/ms)	$RFD_{MAX\,CON}$ (N/ms)	A $POWER_{ECC}$ (W/kg)	P $POWER_{ECC}$ (W/kg)	P POWER P $_{CON}$ (W/kg)	A $POWER_{CON}$ (W/kg)
BMI (Sig)	0.06	0.14	-0.08	-0.21	0.16	0.13	0.05	0.049	-0.13	-0.09	0.49	0.53
	(0.80)	(0.56)	(0.72)	(0.38)	(0.51)	(0.60)	(0.82)	(0.84)	(0.60)	(0.72)	(0.03) *	(0.024) *
	JUMP- TEMPORAL											
	T_{IN} (ms)	T_{ECC} (ms)	T_{CON} (ms)	T P $POWER_{ECC}$ (ms)	T P $POWER_{CON}$ (ms)							
	-0.03	-0.11	-0.05	-0.14	-0.10							
	(0.89)	(0.66)	(0.83)	(0.57)	(0.68)							
	LANDING-KINETICAL											
	F		ROL									
	$F_{MAX\,L}$ (N/kg)	$F_{MIN\,L}$ (N/kg)	LR_{MAX} (BW/S)	$LR_{MAX\text{-}MIN}$ (BW/S)	I (N.S)							
	0.52	-0.13	0.44	0.45	0.27							
	(0.25) *	(0.60)	(0.06)	(0.60)	(0.27)							
	LANDING-TEMPORAL											
	F T (ms)	TS (s)	T P F_{L} (S)	T $F_{MAX\text{-}MIN}$ L (S)								
	0.26	-0.04	-0.47	-0.20								
	(0.28)	(0.86)	**(0.04)***	(0.42)								

*Time Initiation (T_{I}); Eccentric Time (T_{ECC}); Concentric Time (T_{CON}); Maximum Eccentric Force ($F_{ECC\,MAX}$) (N/kg); Maximum Concentric Force ($F_{CON\,MAX}$); Average Power Concentric (A $Power_{CON}$); Average Power Eccentric (A $Power_{ECC}$); Peak Power Concentric (P $Power_{CON}$); Peak Power Concentric (T P $Power_{CON}$); Time Peak Power Eccentric (T P $Power_{ECC}$); RFD Maximum Concentric (RFD_{MAXCON}); RFD Maximum Eccentric (RFD_{MAXECC}); Average RFD Concentric ($ARFD_{CON}$); Average RFD Eccentric ($ARFD_{ECC}$); Peak RFD Concentric ($PRFD_{CON}$); Peak RFD Eccentric ($PRFD_{ECC}$); Time to Stabilization (TS); Impulse (I); Time of Maximum to Minimum Force: (T $F_{max\text{-}min}$ L); Maximum Landing Force ($F_{max\,L}$); Minimum Landing Force ($F_{min\,L}$); Maximum Loading Rate (L R_{max}); Time to Peak Force Landing (TPF); Maximum to Minimum Loading Rate ($LR_{MAX\text{-}MIN}$); Flight Time (FT)

*Significant Correlations ($p<0.05$)

Discussion

The main purpose of this study was to investigate the correlation between body mass index (BMI) and force-time curve variables in jumping and landing of adolescent volleyball players. BMI is used globally to classify humans as overweight, and obese (Status, 1995). BMI is considered as a cheap and easy tool to use compared to the assessment methods of body fat (BF) percentage. However, its use in athletes has been questioned because it is associated with fat mass as well as lean mass (Ode, Pivarnik, Reeves, & Knous, 2007). For instance, by increasing BMI with large amounts of fat and lean mass, a very muscular athlete with low BF can be classified as overweight (Ode et al., 2007). The results of our study showed that there is no significant relationship between eccentric variables and body mass index. Analysis of variables in the concentric phase showed significant correlations between peak power (PP), average power (AP), maximum landing force ($F\ MaxL$) and landing time peak force (TPF_L) with body mass index.

In a review of existing research, no study was found on the relationship between body mass index and force-time curve variables in the jumping and landing skills of adolescent volleyball players. But there are some researches similar to our study that focus on the kinetic variables of jumping and landing of volleyball players (Kirby, McBride, Haines, & Dayne, 2011; Linthorne, 2001; Ode et al., 2007; Pantelis Theodoros Nikolaidis et al., 2015; Status, 1995). Comparisons between groups with different BMI in the mentioned studies have shown that groups with low or normal BMI performed better on physical fitness tests than groups with overweight or obese (i.e, higher BMI) (P. Nikolaidis & Ingebrigtsen, 2013; Nikolaïdis, 2013). Achieving maximum jumping height is one of the most important components of athletic performance in volleyball, basketball and high jump players. Vertical jumping is recognized as an important effective element for optimizing performance in such sports (McMahon, Murphy, Rej, & Comfort, 2017; McMahon, Rej, & Comfort, 2017). Jumping height criteria, strength relative force or absolute strength are outstanding factors in providing performance of athletes. Examining the relative criteria of variables, due to the nature of exercise, can be a more accurate measure of an athlete's ability, because in some sports such as volleyball, basketball and handball, the ability of jumping and fast movements are performance factors that can overcome body weight, or relative criteria force or power can be effective (Riggs & Sheppard, 2009). As shown in Table 2, PP (r = 0.03), F_MaxL (r = 0.25) and TPF (r = 0.04) were significantly associated with body mass index. This shows that the power produced according to the body mass index of each athlete can affect the final jump height, time and peak force at the time of landing (Nikolaïdis, 2013). Power and rate of force development (RFD) are known as the predictive elements in jumping performance, although still debates remain about the priority of these elements but the ability to produce higher power and RFD will lead to higher jumping performance.

In addition, Riggs and Shepard (2009) showed that parameters in the concentric phase at CMJ were significantly correlated with JH. The results presented in this study also showed a significant relationship between concentric phase and body mass index. For example, Kirby et al. (2011) found that peak force was negatively correlated with jump height, indicating that peak force was probably not the best criterion for evaluating vertical jump performance (Kirby et al., 2011; Nikolaïdis, 2013).

According to a study by Lafayi et al. (2014), jumping task is probably one of the key components of performance in volleyball, and the best way to achieve maximum height in jumps is to increase the concentric force and the rate of change of eccentric force. In addition, they examined the correlation between the ratio of eccentric phase time and total time as a function of altitude. The results showed that there was a negative correlation. In addition, our results showed that the eccentric phase time showed a negative correlation with the jump height (r = -.66), which indicates the importance of the short duration of the eccentric phase, but this finding is not significant. It is important to note that decreasing the eccentric phase time increases the involvement of muscle fibers, and given the velocity-time curves, increasing the rate of muscle contraction leads to more force, which can ultimately increase JH (Hody, Croisier, Bury, Rogister, & Leprince, 2019). Of course, it should be noted that a shorter eccentric phase, due to the activity of the muscle spindles and the Golgi tendon, can increase nerve stimulation (Gregory, Brockett, Morgan, Whitehead, & Proske, 2002). In other word, players with the short duration of the eccentric phase have the advantage of jumping higher.

As it is obvious, none of the eccentric variables have a significant relationship with JH. In articles by Jidovtseff et al. (2014), it was presented a categorized list of kinetics variables affecting jumps, the maximum eccentric force affecting the eccentric loading, which helps prevent lower limb deformation during landing and severe landing impacts. This could be a logical reason to express that the eccentric phase focuses more on preventing lower limb injury than on generating power to increase JH. On the other hand, the eccentric phase is important for energy storage, and its duration can affect the amount of energy consumption in the concentric phase. However, in our study, the correlation between the duration of the eccentric phase and JH (r = -.66) was not significant. Jidovtseff et al. (2014) showed that kinetic and kinematic outputs are significantly influenced by jumping style. According to Lintoren (2001), concentric impulse is the main factor that affects the takeoff speed and thus the jump height. This concept was supported by Gonzalez and Marquez (2010), who showed a positive and significant relationship between concentric impulse and vertical jump height, and by Kirby et al. (2011), a very important correlation between net vertical impulse and vertical jump height in CMJ (r = 0.925, p <.0001) was observed. The results of a study by Pantelis Theodoros et al. (2015) showed that jumping and running performance are related to BM body mass status, with overweight basketball players (9 to 12 years old) scoring lower than their normal weight counterparts (Pantelis Theodoros Nikolaidis et al., 2015). Impulse is mainly described in the field of injury prevention although it can indirectly effect the jumping performance through the force transference between the body and the ground as well.

Our study is consistent with the studies cited by Jidutsev et al. (2014), Lafayie et al. (2014), Riggs and Shepard (2009), Kirby et al. (2011) and McMahon, Raj et al. (2017).. Studies have shown that the magnitude of the vertical ground reaction force exerted on the body during the descent, provides a risk factor for injuries in the joints of the ankle, knee, hip and spine (Kijowski et al., 2012; Leuty, 2016). In addition, ground reaction forces can have a significant effect on possible injuries during landing according to the body mass index of each athlete (Kijowski et al., 2012). In other word, higher BMI will lead the players to be susceptible to landing injuries.

Conclusion

Our findings confirmed the importance of average and relative peak power of the concentric phase to attain higher jumps. Since these two variables have the correlation of body mass index on JH, coaches and athletes can focus on them to control athletes' jumping and landing performance. Significant effect of eccentric phase has not been found. Considering nutrition profile of the subjects as well as their mental characteristics assessment are considered as the limitation of the present research. It is suggested to accomplish similar research based on level of the players as well as their gender. Also, other outstanding biomechanical variables such as electrical activity of the selected muscles seems to be another option for the same investigation.

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