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Original Research

Relationship between Temporal Variables and Rate of Force Development during Block Jump Skill in Junior Volleyball Players

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ABSTRACT

There are controversies among the researchers with respect to relationship between rate of force development (RFD) and temporal variables. So the aim of this research was to determine relationship between temporal variables and RFD during block jump skill in junior volleyball players. Twenty one junior male volleyball players of national team participated in this study. Block jump, consisting of an eccentric phase following by an immediate concentric action was performed by participants. The temporal and RFD variables data for the best of three Block jumps were exported and analyzed with the force platform system (Kistler® force platform, 1000 Hz). Pearson product moment correlation coefficient (r) was employed for the analysis of the relationship between RFD and temporal parameters of block jump using SPSS software ver. 21 ($p<0.05$). The results showed that none of the variables have significant correlation with initiation phase and peak RFD of concentric phase. Eccentric phase showed correlation with concentric phase, average RFD of eccentric phase, peak RFD of eccentric phase, and peak RFD of eccentric phase and average RFD of eccentric phases well as average RFD of concentric phase. Concentric phase showed correlation with average RFD of eccentric. Average RFD of eccentric phase also presented correlation with peak RFD of eccentric phase and average RFD of concentric phase. Findings of the present study would be useful for volleyball trainers and coaches who desire to monitor and enhance their athletes' jump performance.

Keywords: Temporal Variables, RFD, Block Jump, Volleyball

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INTRODUCTION

Jumping performance presents high correlation with game's success in volleyball, thus volleyball players trying to maintain maximum jumping performance from the beginning to the end of the game and training (1). In volleyball, jumping performance is obvious at various techniques such as attack, jumping service and block. Block jump in volleyball, includes rapid eccentric muscle contraction followed immediately by concentric muscle contraction, known as the stretch-shortening cycle (SSC), which increases the stored energy and muscle activity (2).

Designing volleyball block, mainly known as a countermovement type jump, consists separated temporal phases including initiation phase by downward movement of center of mass, eccentric phase and concentric phase. As mentioned, block jump is known as a SSC type jump in which changing the direction of center of mass movement from downward to upward is obvious. The least hesitation is believed to play significant role in optimizing jumping performance, known as the amortization phase. So each phase including initiation, eccentric and concentric are important according to their durations.

In the other word, sufficient time needed to produce and transfer force to skeletal systems is one of the most effective mechanisms in SSC. The eccentric phase of SSC provides this opportunity to agonist muscles to generate a substantial force, concurrently providing adequate time to the structures to reach considerable stiffness (3). Precise study of force and temporal curve variables is known to represent valuable and effective factors in jumping performance. Moreover, force time (F-T) curve variables of jumping performance are utilized to assess neuromuscular and biomechanical features related to lower extremity dynamics (4, 5). F-T curve contains kinetic and temporal data in a variety of force derivations during separated phases of eccentric and concentric phases (2, 6, 7).

Rate of force development (RFD) refers to the slope in a force-time curve, which is the development of maximal force in minimal time and is typically used as an index of explosive strength (8). Some investigations have provided documents regarding the significant effects of neural and structural parameters on RFD through dynamic and isometric conditions (9, 10). Maffiuletti et al. (2011) reported relationships between different RFD deviates in isometric contractions with various dynamic performances (10). Also, Laffaye et al. (2014) and McLellan et al. (2011) found correlation between RFD and jumping performance, supporting the significant effect of RFD on jumping performance (6 , 8).There are controversies among the researchers with respect to relationship between RFD and temporal variables. Some investigations report RFD to be an important predictive index for adjusting temporal factors during jumping performance (11-13), while the others have reported a poor relationship between these variables (14-16).Indeed, lees et al. (17) found no significant correlation between RFD and VJ variables measured during an isometric contraction in a horizontal squat position. Kawamori et al. (18) reported a correlation, albeit a nonsignificant one, between dynamic RFD and VJ performance variables ($r = 0.65–0.74$). So many contradictions associated with effects of RFD and temporal variables can be seen, and there is not a direct study about examine these variables with block jump height in junior volleyball players. Based on the background discussed above, the aim of this research was to find relationship between temporal variables and rate of force development during block jump skill in junior volleyball players.

METHODS

Participants

Twenty one junior male volleyball players of national team participated in this study (Age: 17.71±0.90yrs, Weight: 768.28±59.68 N, Height: 195.66±2.93 cm, BMI: 20.47±1.54 Kg/m2 (Mean ± SD)), including eleven outside hitter and ten middle blockers. All the players were right leg and handed. They were excluded from study if they had any musculoskeletal or neurological deficit as well as any injury history that could influence Jumping biomechanics. Written informed consent was obtained prior to testing. The study followed the Declaration of Helsinki's recommendations. Testing procedure was performed in Olympic Laboratory and under supervision of volleyball federation of Islamic Republic of Iran.

Study design

The desigan of the present study was quasi experimental. The athletic task tested in this study was Block jump. This technique is a vertical jump performed with contribution of Stretch-Shortening cycle. The subject starts from ready position with the hands in front of his chest and fingers extended. Block jump 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) while the hands moving upward and totally extended above the head (19, 20). At the beginning of the test, warm up protocol was performed individually for 15 minutes according to official condition 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 were allowed to be more familiar with the appropriate procedure of the test. For minimizing coach role no verbal instructions was 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 block jump and between each trial one minute rest was considered. The temporal and RFD variables data for the best block jump trial were exported and analyzed were conducted by processed in MATLAB programs software (Math Works Inc., Cambridge, MA, USA).

Data analysis

In In order to calculate instantaneous velocity of center of mass, first, instantaneous acceleration of center of mass (COM) was calculated by dividing vertical ground reaction force minus weight of the participant to his mass and then integrating to time by trapezoid method (21). Temporal variables of block Jump were divided into four parts including: initiation, eccentric and concentric to describe the specific feature of each F-T variables at each phases according to the similar investigation(22). These phases were defined as follows (Figure 1):

• Initiation phase (ms) (IP): when the instantaneous velocity of COM started to decrease from zero to its lowest Value.
• Eccentric phase (ms) (ECC): started immediately after the initiation phase and lasted until the instantaneous velocity of COM became equal to zero.
• Concentric phase (ms) (CON): started when the instantaneous velocity of COM became positive, and lasted until the participant left the force platform.
• Rate of force development (N/ms) (RFD) was calculated by subtracting two consecutive vertical force over the frame rate (0.001s).
• Average rate of force development (N/kg/s) (ARFD) (N/kg.s-1) normalized to participants’ mass and,
• Peak rate of force development (N/ms) (PRFD) were then used for further calculations over eccentric and concentric phases separately.

Statistical analysis

To check the normality of distribution of variables Shapiro-Wilk’ test was performed. Statistical descriptive are shown as means (SD) in Table 1. Pearson product moment correlation coefficient (r) was employed for the analysis of the relationship between kinetics and temporal parameters of block jump in participants. Statistical significance was set at $p<0.05$.

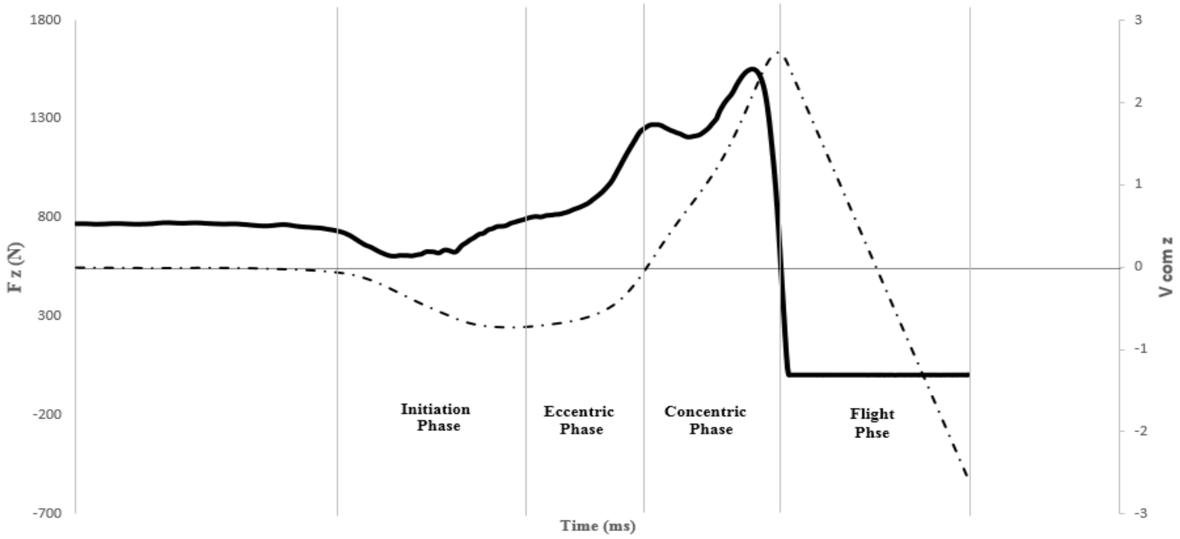

Figure 1- Vertical force (solid line) and instantaneous velocity (dot line) with respect to time form the beginning of Block jump till impact of landing phase are separated according to the velocity curve.

RESULTS

Results of Shapiro-Wilk test showed that the data distribution was normal in all variables of the study. Also Descriptive measures of RFD and Temporal variables during block jump are shown in Table 1.

Table 1. RFD and Temporal variables during block jump

Variables	Mean ± SD
IP (ms)	348.54 ± 110.37
ECC (ms)	288.42 ± 91.40
CON (ms)	34680 ± 76.34
ARFD ECC (N/kg/s)	37.20 ± 18.29
PRFD ECC (N/ms)	6.68 ±2.24
ARFD CON (N/kg/s)	-26.71 ± 9.40
PRFD CON (N/ms)	5.88 ± 1.97

IP= initiation phase, ECC= Eccentric phase, CON= Concentric phase, ARFD ECC= Average Rate of Force Development of Eccentric phase, PRFD ECC== Peak Rate of Force Development of Eccentric phase, ARFD CON= Average Rate of Force Development of Concentric phase, PRFD CON= Peak Rate of Force Development of Concentric phase

In Table 2 demonstrates the correlation between mentioned variables. As it can be observed, none of the variables have significant correlation with IP and PRFD CON, but significant correlations are evident between the other parameters of the study with each other. ECC has correlation with CON ($r = 0.66$, $p = 0.001$), ARFD ECC ($r = -0.79$, $p = 0.000$), PRFD ECC ($r = -0.76$, $p = 0.000$), and A RFD CON ($r = 0.53$, $p = 0.012$). CON variable has correlation with ARFD ECC ($r= -0.47$, $p = 0.031$). ARFD ECC variable has correlation with PRFD ECCE ($r= 0.65$, $p = 0.001$), A RFD CON ($r= -0.87$, $p = 0.000$).

Table 2. Correlation between RFD and Temporal variables during Block Jump Skill

Variables	IP (ms) (sig)	ECC (ms) (sig)	CON (ms) (sig)	ARFD ECC (N/kg/s) (sig)	PRFD ECC (N/ms) (sig)	ARFD CON (N/kg/s) (sig)	PRFD CON (N/ms) (sig)
IP(ms) (sig)	1	0.17 (0.43)	0.13 (0.56)	-0.02 (0.90)	-0.25 (0.26)	0.052 (0.82)	-0.05 (0.80)
ECC (ms) (sig)	0.17 (0.43)	1	0.66 **(0.001)***	-0.79 **(0.000)***	-0.76 **(0.000)***	0.53 **(0.012)***	0.14 (0.52)
CON (ms) (sig)	0.13 (0.56)	0.66 **(0.001)** *	1	-0.47 **(0.031)** *	-0.41 (0.064)	0.22 (0.188)	0.32 (0.152)
A RFD ECC (N/kg/s) (sig)	-0.27 (0.90)	-0.79 **(0.000)** *	-0.47 **(0.031)** *	1	0.65 **(0.001)** *	-0.87 **(0.000)** *	-0.24 (0.288)
P RFD ECC (N/ms) (sig)	-0.25 (0.26)	-0.76 **(0.000)** *	-0.41 (0.064)	0.65 **(0.001)** *	1	-0.38 (0.087)	-0.06 (0.87)
A RFD CON (N/kg/s) (sig)	0.05 (0.82)	0.53 **(0.012)** *	0.29 (0.188)	-0.87 **(0.000)** *	-0.38 (0.087)	1	0.26 (0.255)
P RFD CON (N/ms) (sig)	-0.05 (0.80)	0.14 (0.52)	0.32 (0.15)	-0.24 (0.288)	-0.06 (0.788)	0.26 (0.255)	1

IP= initiation phase, ECC= Eccentric phase, CON= Concentric phase, ARFD ECC= Average Rate of Force Development of Eccentric phase, PRFD ECC= Peak Rate of Force Development of Eccentric phase, ARFD CON= Average Rate of Force Development of Concentric phase, PRFD CON= Peak Rate of Force Development of Concentric phase

* Significant differences ($p<0.05$)

DISCUSSION

In The aim of present study was to determine relashionship of temporal variables and rate of force development during block jump skill in junior volleyball players. The results showed that none of the variables have significant correlation with initiation phase and peak rate of force development of concentric phase but significant correlations are evident between the other parameters of the study. Eccentric phase has correlation with concentric phase, average rate of force development of eccentric phase, peak rate of force development of eccentric phase, peak rate of force development of eccentric phase and average rate of force development of eccentric phases well as average rate of force development of concentric phase. Concentric phase shows correlation with average rate of force development of eccentric. Average rate of force development of eccentric phase also present correlation with peak rate of force development of eccentric phase and average rate of force development of concentric phase.

Force-time (F-T) curve characteristics of jumping are globally referenced as the main descriptors of athletic performance, particularly for volleyball players (23). As far as scientific researches show there is no specific study about correlation between RFD and temporal variables extracted from force-time curve during block jump in volleyball players. Indeed most of surveys focused on the effects of various training program on these parameters during jumping (2, 24) and the others emphasized on correlation of mentioned variables upon jump heights or flight time during jumping (25). For instance Sarvestan et.al (2020) revealed that the RFD, concentric net impulse, and modified reactive strength had significant correlation with spike jump height, while no significant correlation was observed between velocity, force, or power measures with this

kind of jump (23). Thng et.al (2020) confirmed that the several lower body force-time characteristics, in particular concentric impulse, were significantly related to swim start performance in national and international level swimmers before squat jump (26).
Considering similar investigation to ours, Laffaye et.al (2013) have studied about determination on eccentric rate of force development on jumping performance and in accordance with ours (27). They stated that jumping higher requires a motor strategy based on the optimization of the stretch shortening cycle function, by increasing the ECC–RFD and minimizing the ECC phase which results in higher level of force as well as improvement of the vertical jump performance. The RFD seems to be a better predictor of jumping performance than the previous methods, by summarizing the ability of the muscle–tendons system to store and release efficiently elastic energy as well as activating the stretch reflex (27). McLellan et al. (2011) reported a relationship between different RFD calculations (i.e. average and peak) and unloaded jump performance on a force plate, thus suggesting that rapid force production is a prerequisite for higher jumps (8). However, it should be pointed out that these previous calculations were related to force production rates recorded during the eccentric phase of the countermovement as the greater force increments are typically observed during this phase (27).
As mentioned above, we couldn't find any significant correlations between initiation phase (IP) of jumping with other parameters. This phase is primary stage in jumping and maybe we can say that it is a prerequisite of following ECC and CON phases. So despite no correlation exists with them, IP can prepare elastic component of lower limb for better entrance to ECC phase and in the other word it saves enough energy for explosive phases of jumping but it doesn't influence in force- time slope or timing of flight. Also we couldn't find a study about correlation of RFD and other temporal variables during block jump performance in volleyball players. Critical elements in performing block jumps during the game include height of the jump, quickness of the jump's execution, and timing of initiating the jump. The appropriate combination of these elements will correctly position the blocker at the optimal height as well as the right instant to block the ball. In block jump, the player start from a static position with preliminary downward movement (eccentric muscle contraction) followed by an immediate upward movement (concentric muscle contraction). This natural pattern of eccentric followed by concentric muscle contraction with short amortization phase, known as the stretch-shortening cycle (SSC). The practical importance of the SSC is to enhance and facilitate these activities by using the elasticity of the muscle and the stretch reflex to enhance muscle output (28). The results of this study, also confirmed relationship between these two important phase (i.e. ECC and CON) and ECC phase showed more correlation with other parameters. So in order to perform an efficient and successful block jump, eccentric phase may play an important role. The results showed significant correlation between ECC phase with most of the other variables such as CON, ARFD ECC, PRFD ECC, and ARFD CON. Also, the significant correlation between RFD measures suggests that block jump performance primarily influenced by the ability to develop force rapidly (RFD) and to a lesser extent maximal strength. The use of PRFD as a measure of block jump performance in this dynamic explosive techniques and concentric RFD, which is defined as the capability of muscle fibers to rapidly develop force measures, has been verified to have large degrees of association with jump height. Nevertheless, a variety of results regarding the relationships between RFD values and jump variables seems to be problematic in the tracking of neuromuscular status to assess athletic jump performance (4).
Interestingly, the results of current study showed that the peak and average RFD values which were the strongest predictors among all the F-T curve variables, had significant correlation with each other in specific ECC and CON phases and also temporal variables. These outcomes indicate that the capability of the lower-limb muscles to develop the produced force could play a vital role in jump height during game-like conditions. These findings support the outcomes of a study conducted by (8), who reported a strong positive relationship between RFD and vertical jump height. Such a meaningful contribution to the prediction of jump demonstrates that attackers efficiently activate and govern the coupling between the neural and muscular systems to execute a highly coordinated, rapid contraction and to jump higher (29). Simply explained, attackers increase the center of mass (COM) horizontal velocity in triple-approach running and then transfer it to COM vertical velocity in the planting phase using the SSC function of the ankle, knee, and hip joint extensors (29, 30). Achieving such coordinated, harmonious activation of muscles in a relatively short period of time demands a highly powerful neuromuscular status, which RFD could reliably exhibit in athletic jumping performance. From a practical point of view, and as illustrated by the outcomes, it is not the amount of applied force that contributes in jump height but rather the pattern of applying the force that paves

the way for a higher jump height, which is governed. To this effect, it is highly suggested to enhance the sports-specific jumping strategy, along with strengthening the muscles, in order to efficiently recruit the best muscle function during jump performance.

CONCLUSION

Our findings confirmed the importance of RFD and temporal variables and their correlations with each other. Appropriate timing of eccentric and concentric phases during Block jump should be considered for players to achieve optimum height. Also, inter relationships between peak and average of RFD provide outstanding benefits to modify jumping technique in volleyball players. So biomechanics researchers, coaches and athletes should focus on these variables of volleyball players' jumping. Findings of the present study would be useful for volleyball trainers and coaches who desire to monitor and enhance their athletes' jump performance.

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چکیده فارسی

رابطه بین متغیرهای زمانی و نرخ توسعه نیرو در اجرای مهارت دفاع روی تور والیبالیست های جوان

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در حوزه بررسی ارتباط بین متغیرهای RFD و متغیرهای زمانی بین محققان اختلاف نظر وجود دارد. بنابراین هدف از این تحقیق حاضر بررسی رابطه میان متغیرهای زمانی و نرخ توسعه نیرو در حین مهارت دفاع روی تور در والیبالیست های جوان بود. در این مطالعه ۲۱ بازیکن والیبالیست جوان تیم ملی به عنوان آزمودنی شرکت کردند. جمع آوری اطلاعات توسط با کالیبراسیون سیستم صفحه نیرو (®Kistler، 1000 هرتز) آغاز شد. مهارت پرش دفاع روی تور، متشکل از یک مرحله اکسنتریک و به دنبال آن یک مرحله کانسنتریک، توسط شرکت کنندگان انجام شد. داده های مربوط به متغیرهای زمانی و RFD برای بهترین پرش از میان سه پرش انجام شده، تحلیل شد. برای تجزیه و تحلیل رابطه بین RFD و پارامترهای زمانی دفاع روی تور، از نرم افزار SPSS و آزمون ضریب همبستگی پیرسون استفاده گردید ($p < 0.05$). نتایج نشان داد که متغیرهای زمان فاز شروع حرکت و نرخ توسعه نیروی کانسنتریک، با هیچ کدام یک از متغیرهای دیگر ارتباط معناداری نداشتند. زمان فاز اکسنتریک، با زمان فاز کانسنتریک، میانگین نرخ توسعه نیرو در فاز اکسنتریک، حداکثر نرخ توسعه نیرو در فاز کانسنتریک، حداکثر نرخ توسعه نیرو در فاز اکسنتریک، میانگین نرخ توسعه نیرو در فاز اکسنتریک و میانگین نرخ توسعه نیرو در فاز کانسنتریک معنادار بود. زمان فاز کانسنتریک نیز با میانگین نرخ توسعه نیروی اکسنتریک ارتباط معناداری داشت. میانگین نرخ توسعه نیروی اکسنتریک نیز دارای ارتباط معناداری با حداکثر نرخ توسعه نیروی اکسنتریک و کانسنتریک بود. یافته های مطالعه حاضر ابزار مفیدی است که مربیان و متخصصین والیبال می توانند از آن برای نظارت و بهینه سازی عملکرد پرش در والیبالیست ها بهره مند شوند.

کلمات کلیدی: متغیرهای زمانی، نرخ توسعه نیرو، دفاع روی تور، والیبال