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Article

Stretch-Shortening Cycle in Countermovement Jump: Exclusive Review of Force-Time Curve Variables in Eccentric and Concentric Phases

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Abstract: The importance of vertical jump in sport fields and rehabilitation is widely recognized. Furthermore, Force-Time variables of vertical jump are factors affecting jumping height. Exclusive review of each of this variables, in eccentric and concentric phases, can lead to a specific focus on them during jumping exercises. So, the aims of his study were to a) reviewing the relationship between force-time curve variables of eccentric and concentric phases with jump height and b) description of this variables in Iran national youth volleyball players society. This is an observational study. 12 elite volleyball player (Male, Iran national youth volleyball players, 17±0.7 years) have participated in this study. Correlation between Force-Time variables - included peak force (PF), relative peak force (RPP), peak power (PP), average power (AP), relative peak power (RPP), and Modified Reactive Strength Index (MRSI) - in eccentric and concentric phases and ultimate jump height has been studied. Results showed that the average power (r=0.7) and relative peak force (r=0.75) of concentric phase and MRSI (r=0.83) have significant correlation with ultimate jump height (JH). Relative peak power and average power of concentric phase can massively effect Jump Height in sports like volleyball, which vertical jump is an integral part of them. Focus on both of these factors, which has been studied in this research, in training programs, can improve athlete jump performance significantly.

Keywords: stretch-shortening cycle; countermovement jump; force-time curve variables; eccentric; concentric; volleyball

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1. Introduction

Vertical jump is an integral part of preparation exercises in most of sports, which needs high velocity and power. Many researches have focused on athlete's vertical jump, especially height of jump [24, 25, 26]. Vertical jump is also uses for assessing the explosive power of lower extremity and forecasting and monitoring athletes. Power and force are known as a relative factors with sport performance [1, 28]. Ability of producing high power by lower extremity is very important in most of sports, such as soccer, ice hockey, volleyball, basketball and run and field [1, 10]. Most of previous researches assessed lower extremity power by counter movement jump (CMJ) [12]. CMJ is a kind of vertical jumps and most useable test for assessing the neuromuscular coordination of athletes [3]. In

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addition, CMJ uses for assessing the fitness level of injured athlete, after rehabilitation period and to detecting return to play [2, 8, 20]. Force-Time curve variables of CMJ are used to assess neuromuscular and biomechanical features related to lower extremity dynamic [3, 12].

Vertical jump tests are used with various aims, such as assessing elite athletes force and power, which participate in competitions regularly [4]. McGinnis et al. have used CMJ to assess the effect of fatigue on performance [15]. Olsson et al. showed CMJ and hopping could be used for assessing athlete's performance, after Achilles tendon tearing [20]. Previous researches have shown CMJ has appropriate validity for assessing explosive power of knee extensors. The research that has conducted by Markovic (2004) showed that CMJ is the most prestigious tool for lower extremity power assessment [14]. It seems CMJ repeatedly used in most of sports, like soccer, volleyball and basketball.

CMJ includes rapid eccentric, then concentric activity of muscle, which is known as stretch-shortening cycle (SSC). In the Schmidtbleicher's category (1992), CMJ placed in slow SSC for the case that its contact time is greater than 0.25 second [27]. SCC nature is known as rapid concentric contraction, after rapid eccentric contraction, which increases stored energy and muscle activity [4]. Pre-activation, activating muscle structures before implementation, rate of change of muscle length in comparison with rate of change of tendon and stretching reflexes role are the other effective aspects in SSC. Factors affecting SSC, in turn, increase height of jump by increasing center of mass vertical velocity, which increased by lower extremity power during concentric phase. Sufficient time for producing and transferring force to skeletal system is one of the most effective mechanisms in SSC. Eccentric phase of SSC gives this opportunity to agonist muscles to generate significant force, and also gives enough time to the structures to reach considerable stiffness [10].

Achieving to relative peak power in different sports, such as volleyball and basketball, which vertical jump is an integral part of them, can effect ultimate height. Riggs & Shepherd (2009) stated that relative peak power and average power have significant correlation with CMJ [23]. Since power is normalized with body weight, it could be pointed out that, individual relative peak power has considerable effect on performance and reaching to ultimate height. Exclusive review of Force-Time curve variables in CMJ can help us finding effective factors in jump height. Peak power (PP), peak velocity (PV), relative force (RF), average force (AF) and peak force (PF) are reviewed as an effective variables in concentric and eccentric phases in most researches [4, 13, 23].

Based on the research conducted by Lafaei et al., the best way to reach maximum height in jumps is to increase concentric force and rate of change of eccentric force [13]. In addition, they searched the correlation between the ratio of eccentric phase time and total time with ultimate height, and results showed the negative correlation [13]. Also, Pupo et al. have shown the ultimate height has positive correlation with maximum velocity and normalized maximum force [13]. They expressed, as well, power has significant correlation with the other force-time curve variables [13].

Vertical jump is an integral part of preparation exercises in most of sports, such as volleyball and basketball. High jump height and high power output capability are presented as a key factors of success in most of sports [5, 29]. Since both of these two factors, in CMJ, can be in the form of a functional and dynamic, finding the effective variables on ultimate height and generated power is so important. Reviewing force-time curve variables in different phases of CMJ can be a good index for exclusive and fractionation review of vertical jump performance. Based on background discussed above, final aims of this research are a) reviewing the relationship between eccentric phase force-time

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curve variables with jump height and b) description of this variables in Iran national youth volleyball players society.

2. Materials and Methods

2.1. Subjects

Twelve youth male elite volleyball player participated in this study; 3 setters, 3 middle blockers, 3 wing spikers and 3 opposite spikers. Anthropometrical features and training experience of participants have been written in table 1. All of the players were playing in Iran pro-league and national team. Participants were signed study purposes and methods explanations, in detail. Written informed consent was provided prior to testing and the study was pre-approved by health and sport science faculty of university of Tehran.

Table 1. Anthropometrical features of participants

No.	Age (Year)	Height (cm)	Weight (kg)	Experience (Year)
12	17±0.7	189±8.3	83±6.1	5.8+1.9

2.2. Instruments and Procedure

Following a dynamic warm-up for 15 minutes, subjects performed three CMJs (interspersed with 3 minute of rest to prevent fatigue) to a self-selected depth [16, 17]. Subjects were instructed to perform the CMJs as fast and as high as possible, whilst keeping their arms akimbo (figure 1). Participants stood still for the initial one second of the data collection period [17] to allow for the determination of body weight post-testing. All CMJs were recorded at 1000 Hz via a Kistler type 9281C force platform and Bioware 5. 11 software (Kistler Instruments Inc., Amherst, NY, USA). The raw vertical force-time data for each CMJ trial were exported and analyzed using Microsoft Excel 2013.

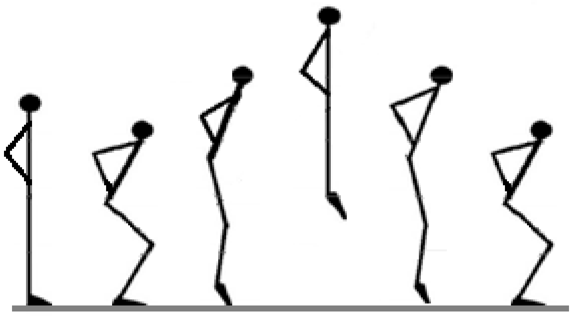

Figure 1. Manner of performing CMJ – Akimbo style

2.3. Data Analysis

Instantaneous COM velocity was calculated by dividing vertical force (excluding body weight) by body mass and then integrating the product using the trapezoid rule. Displacement was also calculated via double integration of force-time curve data. Instantaneous power was calculated by multiplying vertical force and velocity data at each time point and COM displacement was determined by twice integrating vertical force data [17, 21]. Eccentric and concentric peak force, peak power, and peak velocity were defined as the maximum values attained during the eccentric and concentric phases of the jump. Impulse was calculated during both the eccentric and concentric phases of the jump as the area under the net force-time curve (excluding body weight) using the trapezoid rule [11]. All kinetic data were divided by body mass to allow for a normalized comparison

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of these data between sexes. Jump height was derived from the vertical velocity at take-off [19]. A modified reactive strength index (MRSI) was calculated as the jump height (m) divided by movement time (s) [7]. Finally, stiffness was calculated from changes between start point of unweighting phase to lower position of COM, which had been calculated via double integration of force-time data [18].

Some researches divided CMJ into three phases –unweighting, eccentric and concentric [1, 6, 17]. In this study, we have also divided CMJ, or SSC, to unweighting, eccentric and concentric to review the specific impacts of each force-time curve variables on jump height. Although we explain all three phases below, but we are going to review just eccentric and concentric phases in discussion. These phases were defined as follows:

- Unweighting phase: This phase starts when the velocity measures starts to decrease from zero and finishes when it measures reach to its lowest one (A to B).
- Eccentric phase: This phase starts immediately after unweighting phase and lasts till the velocity of center of mass becomes equal to zero (B to C).
- Concentric phase: Concentric phase starts when the velocity of center of mass becomes positive and lasts till participant leaves the force platform (C to take off).

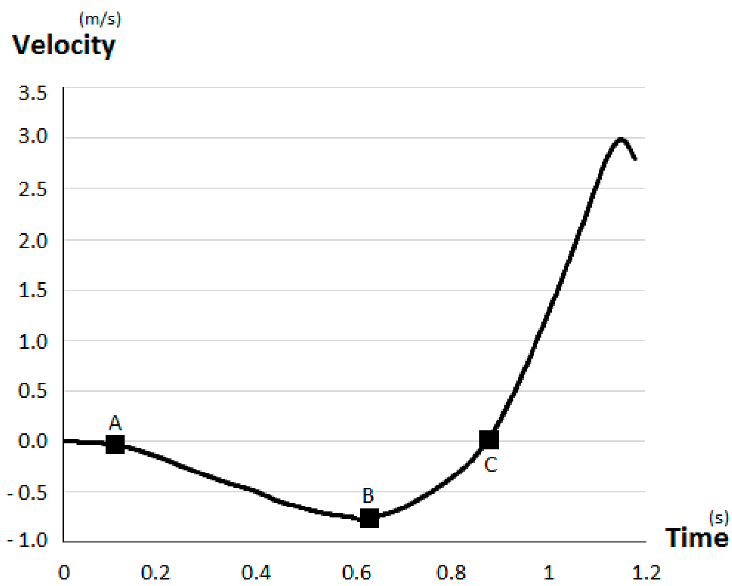

Figure 2. CMJ phases according to V-T curve: (A) start of unweighting phase, (B) start of eccentric phase, (C) start of concentric phase

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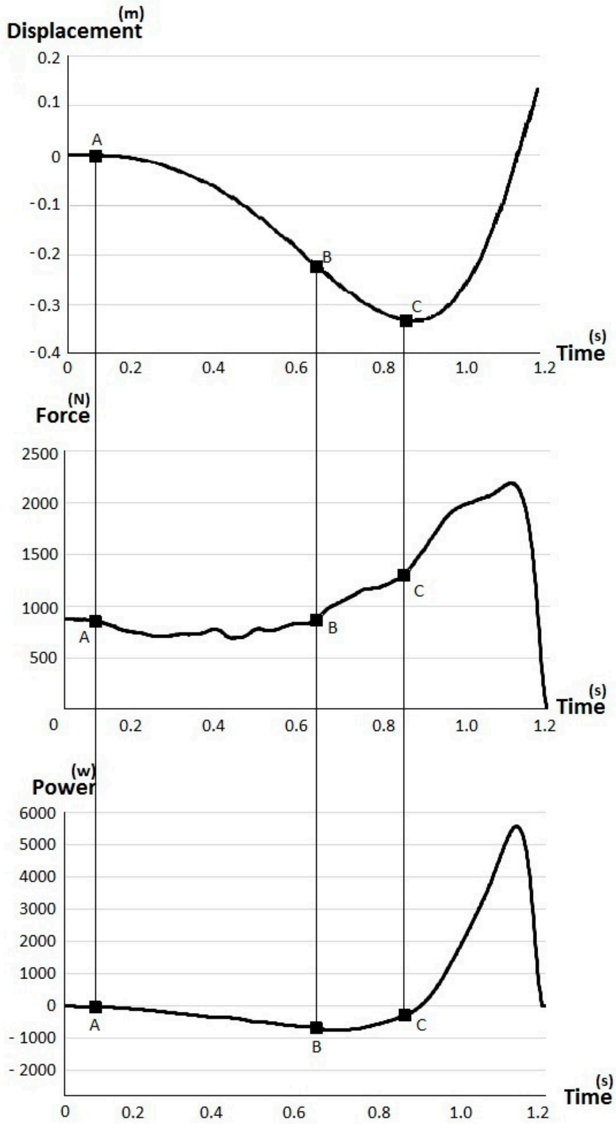

Figure 3. CMJ phases in D-T, F-T and P-T curves

2.4. Statistical Analysis

To determine the relationships among eccentric and concentric phase's variables, Impulse and MRSI with ultimate jump height, Pearson Product Moment correlations were performed. Then, the statistics All Statistical tests were using a significance level of $p \leq 0.05$ by 22nd version of SPSS.

3. Results

Descriptive measures of force-time variables in eccentric and concentric phases are showed in table 2.

Table 2. Descriptive measures of force-time variables in eccentric and concentric phases.

Variables		Descriptive Measures
	TTE	183±43
	TTC	338±3
Time (ms)	TtE	440±7
	TtC	627±7
	TtPPE	74±2

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	TtPPC	255±4
	JTT	965±5
Velocity (m/s)	PVE	1.25±0.25
	PVC	2.98±0.19
Force (N)	PFE	857±312
	PFC	1874±246
	RPFE	8.3±0.25
	RPFC	20.4±2.23
	PPE	1323±4
	PPC	4696±8
	APE	1020±3
	APC	235±4
	RPPE	12.03±0.3
	RPPC	52.75±0.7
Impulse (N.m)	IMPE	1.0±0.3
	IMPC	2.5±0.6
MRSI		0.364±0.06
Jump Height (m)		0.37±0.05

Total Time Eccentric (TTE), Total Time Concentric (TTC), Time to Eccentric (TtE), Time to Concentric (TtC), Time to Peak Power Eccentric (TtPPE) and Time to Peak Power Eccentric (TtPPE), Jump total time (JTT), Peak Force Eccentric (PFE), Peak Force Concentric (PFC), Relative Peak Force Eccentric (RPFE) and Relative Peak Force Concentric (RPFC), Total Time Eccentric (TTE), Total Time Concentric (TTC), Time to Eccentric (TtE), Time to Concentric (TtC), Time to Peak Power Eccentric (TtPPE) and Time to Peak Power Eccentric (TtPPE), Peak Velocity Eccentric (PVE), Peak Velocity Concentric (PVC), Eccentric impulse (IMPE), Concentric impulse (IMPC) and Modified reactive strength (MRSI).

Tables 3 shows the correlation between force time variables of eccentric and concentric phases with ultimate jump height.

Table 3. Correlation between force time variables of concentric and ultimate jump height.

Variables	JH
TTE	-0.49
TTC	-0.57
TtE	-0.04
TtC	-0.33
TtPPE	0.10
TtPPC	-0.38
PFE	0.34
PFC	0.32
RPFE	0.34
RPFC	0.28
PPE	-0.27

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PPC	0.58
APE	-0.22
APC	0.70 *
RPPE	-0.30
RPPC	0.75 *
PVE	-0.25
PVC	0.98 **
IMPE	0.31
IMPC	0.02
MRSI	0.83 **

*** p<0.05. ** p<0.01**

As can be seen in table 3, none of eccentric variables have significant correlation with ultimate jump height, while Average power (r=0.7), Relative peak power (r=0.75), Peak velocity (r=0.98) of concentric phase and Modified reactive strength index (r=0.83) have significant correlation with JH.

4. Discussion

Achieving to maximum jump height, is the first and the most important purpose of coaches, volleyball players, basketball players and height jumpers. Vertical jump is detected as an important effective factor in such sports [24, 25]. JH measures, power and force, whether relative or absolute, are spiffing factors for presenting athlete performance. In a study, that has conducted (Riggs and Shepherd, 2009) on elite beach volleyball players, relative peak power has strong correlation with JH (r=0.9) [23]. Reviewing the relative measures of variables can be a more precise criteria of athlete capability, due to the nature of sport, because in some sports, like volleyball, basketball and handball, the ability of jump and rapid movements are factors affecting performance, which the ability to overcoming body weight or relative measures of force or power could be effective [23]. As it could be seen in table 3, concentric relative peak power has significant correlation with JH (r=0.75). It could indicate that, power generated by each athlete can specifically effects his/her ultimate jump height. Therefore, volleyball players could help by offer some developing power exercises, such as plyometric or weightlifting movements to improve their jumping performance.

Additionally, Riggs and Shepherd mentioned that the average power of concentric phase in CMJ has significant correlation with JH (r=0.67). They are, also, pointed out the average power and relative peak power of concentric phase have impact on JH [23]. Results presented in this study show a significant correlation between average power of concentric phase and JH (r=0.7), which shows the effect of this parameter on JH (Table 3). Pupo et al. pointed out that concentric peak force (PFC) has weak correlation with (r=0.05) JH [22].According to the results showed in table 3, concentric peak force has weak correlation JH (r=0.32), and this can be an explanation for that the absolute measures of force can’t be a good predictor for improving JH, as well as relative measures.

Based on the study conducted by Laffaye et al. one of the ways that leads increasing jump height is reducing eccentric phase time [13]. Table 3 shows that the total time of eccentric phase has negative correlation with JH (r=-0.49) which shows the importance of short eccentric phase duration. On the other hand, it could be mentioned that reducing eccentric phase time leads to increasing recruitment of muscle fibers, and, according to V-T curve, increase in muscle contraction velocity results in generating more force, which can increase JH. Of course it should be noted that faster eccentric phase can increase neurostimulation, due to muscle spindles and Golgi-Tendon organs activity.

As it could be seen in table 3, none of eccentric variables has significant correlation with ultimate jump height. In Jidovtseff et al. research's division of effective variables in jumps, maximum force of eccentric phase has impact on eccentric loading, which helps in avoiding of lower limb deformation in landing and landing impact [9]. This explanation can be a good reason for this statement that, eccentric phase is largely focused on lower limb injury prevention rather than producing force to increase jump height. Additionally, as Jidovtseff et al. mentioned, kinetic and kinematic outputs are extremely affected by jump style [9]. All of subjects ware young players and it can well explain that the differences of participants jump performance are influenced by their less training experience.

Eventually, One of this study limitations was small sample size, which according to statistics, is one of the most important factors in statistical power. For this reason, the small sample size in this study, must be taken into consideration.

5. Conclusions

This study's results highlight the importance of average and relative peak power of concentric phase to access higher jump. Once this two variables and peak velocity of concentric phase have undeniable effect on ultimate jump height, coaches and athletes can focus on variables, such as peak force, peak power and average power of eccentric phase, which have significant effect on this parameters. On the other hand, as kinematics and kinetics outputs are significantly affect by jump style, it should be note that some parameters, such as training experience, area of playing and player's game position may have effect on this parameters, which might leads to misinterpret in designing a training program.

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Conflicts of Interest: The authors declare no conflict of interest.

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