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Relationships between Amortization Force and Kinetics Variables during Jumping and Landing

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ABSTRACT

Background: Force-time curve variables of countermovement jump are utilized to assess neuromuscular and biomechanical features related to lower extremity dynamics. The amortization phase is the transition phase between eccentric and concentric muscle activity, and it is related to performance during jumping and agility activities. This study determines the relationship between Amortization Force and kinetics variables during a jumping and landing task.

Methods: Seventeen junior professional male volleyball players performed three counter-movement jumps with maximum effort. The function of the stretch-shortening cycle of the legs concerning the jumping movement has been evaluated using the block jump skill on a dual-force platform (Kistler, CH). Kinetics data from Force - Time curve variables were calculated using MATLAB software (Math Works Inc., Cambridge, MA, USA) for the best jump trial. Multiple Stepwise Regression analysis was used to estimate the relationship between amortization force and other kinetic variables during jumping and landing as well as the magnitude coefficient of each variable.

Results: Significant relationship between amortization force and other kinetic variables in the first step of stepwise regression models ($p<0.05$).

Conclusions: These data may suggest that conditioning coaches should identify their players' preferred positions and incorporate a specific training program to enhance the players' power.

KEYWORDS
Countermovement Jump, Center of Mass, Eccentric Phase, Concentric Phase, Amortization phase, Force-Time Curve.

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Introduction

Jumping and landing are frequently part of many sports and often used in athletic training in an attempt to improve explosive performance [1]. Jumping is also used to test lower extremity power, with performance traditionally being solely measured by jump height [1]. The maximum force of the eccentric phase of a countermovement jump impacts eccentric loading, which helps control lower limbs, and severe impacts during landing [2]. Landing occurs when the ground reaction force begins to increase on contact, with the peak landing force depicted as the largest spike following ground contact [3]. During landing, there are high levels of eccentric force to be absorbed [4]. Depending on the load and depth, the eccentric Rate of Force Development (RFD) may be highly varied but maximized with the quarter depth and light loads [5]. As this movement begins, impulse drops below the bodyweight baseline [6]. Peak power, peak velocity, relative force, average force, and peak force are highlighted as effective variables in concentric and eccentric phases in most research studies [7-9]. Typically, high ground reaction forces (GRFs) are generated by athletes in various sports given the dynamic and explosive nature of jump landings in training and competition [10-12]. Adhering to fundamental jump-landing mechanics may help to reduce both the rate and magnitude of GRF during impact [13].

Force-time curve variables of countermovement jump (CMJ) are utilized to assess neuromuscular and biomechanical features related to lower extremity dynamics [14, 15]. Assessing the CMJ, force-time curve phase characteristics between training phases indicated that stronger athletes responded more favorably as compared to weaker athletes throughout training [2]. Providing additional information regarding both the influence of additional measures of strength and explosiveness on the countermovement force-time curve characteristics as well as the behavior of jumping and landing will greatly enhance how these characteristics may be used to monitor an athlete's performance state [2].

In general, the force-time curve during jumping and landing may be divided into four sub-phases, including eccentric, amortization, concentric, and landing phases, and many kinetic variables can be extracted from each of these phases. A recent research study observed a strong relationship between jump performance and force production during the eccentric and amortization phases [5]. The eccentric and amortization phases have been previously undervalued for jump performance because they do not correlate to jump height [5]. Amortization is the transition phase between eccentric and concentric muscle activity, and it is related to performance during jumping and agility activities [16]. The amortization phase was identified as beginning when the center of mass (COM) position was 1 cm higher than the lowest position, ending 1 cm after reaching the lowest position [5]. Therefore, individual joints may be going through amortization before or after the COM's amortization phase [5]. The short amortization phase has been highlighted to represent proper levels of neuromuscular reactivity, while a longer phase is often associated with the potentiation of neuromuscular protective mechanisms, such as the inverse mitotic (Golgi tendon) reflex [17]. Therefore, if an athlete can improve their eccentric and amortization force production at higher relative loads, they may see improved stretch-shortening cycle capacity during competition when abrupt changes of direction from high speeds or with external load are demanded [5].

Amortization phase production variables include amortization force and amortization time [5]. Amortization force does not increase with increasing loads [5]. Rather, increased stretch phase duration and decreased relative magnitudes increase amortization time, resulting in lower force production during the amortization phase while transitioning from eccentric to concentric motion [2].

It is not clear how other kinetic variables influence amortization force production during jumping and landing, but it is important to note that the amortization phase overlaps into both eccentric and concentric phases [5] and could be influenced by other kinetic and landing variables in these two phases. Several studies have investigated the correlations between kinetic variables extracted from the force-time curve of jumping and landing [5, 8, 21, 22]. Nevertheless, to the authors' knowledge, no study has yet examined the amortization force influenced by other kinetic variables during jumping and landing. As amortization force is an essential parameter in jump, this study aimed to explore the relationship between amortization force and selected kinetics variables and landing during jumping.

Material and Methods

Participants

Seventeen junior male volleyball players participated in this study (Age: 17.82±0.95 years, Body Mass: 73.97±61.60 kg, Height: 195.24±2.77 cm). Participants were experienced volleyball players, participating in routine volleyball training for 3 sessions per week. Exclusion criteria for the study included individuals who had any existing musculoskeletal or neurological condition that could influence the jumping and landing task. Written informed consent was obtained before testing in line with the Declaration of Helsinki [53]. This study was approved by the Research Ethics Committee of the Sport Sciences Research Institute of Iran (code: IR.SSRI.REC.1151). All testing was performed in the Olympic Laboratory and under the supervision of the Islamic Republic of Iran Volleyball Federation.

Study Design

At the beginning of the test, a warm-up protocol was performed individually for 15 minutes according to the official condition of the volleyball training sessions or games. The athletic task tested in this study was a countermovement jump (CMJ). This technique is performed with the contribution of a stretch-shortening cycle [46]. Participants started from the ready position with their hands in front of their chest and fingers extended. The CMJ began with a preliminary downward movement by flexing at the knees and hips (eccentric phase), and then the knees and hips were immediately extended again to jump vertically (concentric phase) while the hands moved upward and extended above the head [31, 32]. The athletes were encouraged to jump "as high as possible". For each participant, three to five repetitions were allowed for familiarization with the appropriate procedure of the test. To minimize coaching, no verbal instructions were described for players.

Kinetic data was collected using a force platform system (Kistler®, CHE) at 1000 Hz. Participants were asked to perform three maximal jumps, and between each trial, one minute of rest was given to participants to minimize fatigue, according to the explosive nature of the volleyball and its requirement to perform the highest jump in the match. The best of the three was considered for further analysis using kinetic data from Force-Time curve variables, calculated for the best jump trial [47, 54]. Data were exported and processed in MATLAB programs software (Math Works Inc., Cambridge, MA, USA).

Data Analysis

Preprocessing

To calculate the instantaneous velocity of the center of mass (COM), first, the instantaneous acceleration of the center of mass was calculated by dividing vertical ground reaction force minus the weight of the participant by his mass and then integrating concerning time using the trapezoid method [33].

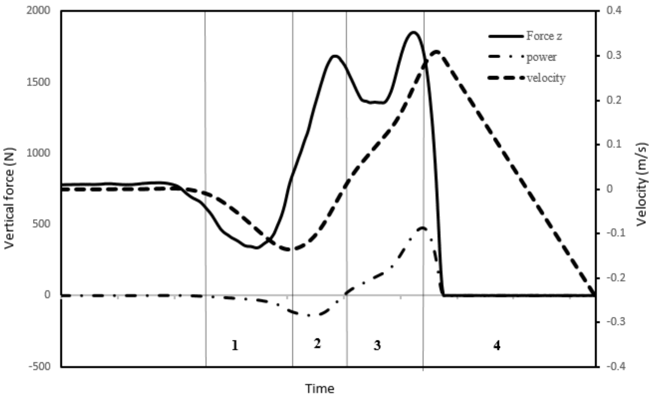

Figure 1. Jumping Graph. Vertical force, Instantaneous Velocity, and Power concerning Time from the beginning of the Block Jump till the impact of landing are shown. The Amortization phase is expressed by the red circle between eccentric and concentric phases, which are separated according to the Velocity curve: 1) Initiation phase, 2) Eccentric phase, 3) Concentric phase, and 4) Airborne phase.

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

• Initiation Phase (IP)¬(m_s): when the instantaneous velocity of COM started to decrease from zero to its lowest Value.

• Eccentric Phase (ECC)¬(m_s): started immediately after the initiation phase and lasted until the instantaneous velocity of COM became equal to zero.

• Concentric Phase (CON)¬ (m_s): started when the instantaneous velocity of COM became positive and lasted until the participant left the force platform.

• Amortization Phase (AM)¬(m_s): The time delay between overcoming the negative work of the eccentric pre-stretch to generating the force production and accelerating the muscle contraction and the elastic recoil in the direction of the stretch-shortening cycle.

Following this stage, power was calculated in the vertical direction for each frame according to Equation 1 [13]:

$$Pi = Fi \times Vi \qquad \text{Equation 1.}$$

Other kinetic variables of jump were divided into the following subsets during eccentric and concentric, according to a similar investigation [35, 36] (Figure 1):

• Amortization Force (AM Force) (N/kg): Vertical force magnitude in the moment of changing eccentric to concentric phases normalized to the body weight.

• Maximum Eccentric Force (FECC MAX) (N/kg): Maximum force calculated from eccentric phase normalized to body weight.

• Maximum Concentric Force (FCON 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

• RFD Maximum Concentric (RFD MAX CON) (N/m_s): Calculated by dividing the peak force of the concentric phase by the time elapsed between the beginning of the concentric phase until the peak force normalized to body mass.

• RFD Maximum Eccentric (RFD MAX ECC) (N/m_s): Peak of eccentric force divided by time elapsed between the beginning of eccentric phase until peak force, normalized to body mass.

• Average RFD Concentric (ARFD 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 ECC) (N/kg/s): Average of RFD calculated between each consecutive frame in concentric phase normalized to body mass

• Peak RFD Concentric (PRFD CON) (N/m_s): Peak value of force divided by elapsed time from the beginning of the concentric phase until the peak force normalized to body mass.

• Peak RFD Eccentric (PRFD ECC) (N/m_s): Peak value of force divided by elapsed time from the beginning of eccentric phase until the peak force normalized to body mass.

Then, the kinetic curve variables of the landing were divided into the following subsets during a similar investigation [35,36] (Figure 2):

• Impulse (I) (N.S): The area below the force-time curve of landing from contact to stability.

• Maximum Landing Force (F_(max_L)) (N/kg): The highest peak of force derived from force plate output in the landing phase normalized to the body weight.

• Minimum Landing Force (F_(min_L)) (N/kg): The lowest peak of force derived from force plate output in the 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.

• Maximum to Minimum Loading Rate (LR MAX-MIN) (BW/S): Difference between the maximum and minimum force of landing divided by interval time between two peaks

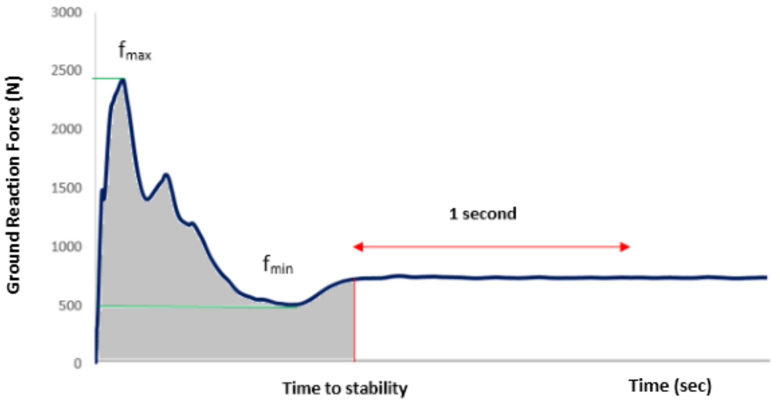

Figure 2. Landing Graph (the grey area represents Impulse).

Statistical analysis

To check the normality of variable distribution, Shapiro-Wilk's test was performed. Multiple Stepwise Regression analysis was used to estimate the relationship between amortization force and other kinetic variables during jumping and landing as well as the magnitude coefficient of each variable. All stages of this part are done with SPPS version 21 (IBM, USA) software. Statistical significance was set at $p<0.05$.

Results

The results of the Shapiro-Wilk test indicated a normal distribution of the data of the variables. Table 1 shows descriptive results of variables in the present study.

Table1. Mean ± SD of the variables

Variables	Mean ± SD	Variables	Mean ± SD
A RFD ECC (N/m$_s$)	38.44 ± 18.61	P RFD ECC (N/m$_s$)	6.80 ± 2.41
A RFD CoN (N/m$_s$)	-27.16 ± 9.37	P RFD CON (N/m$_s$)	5.83 ± 2.01
F ECC MAX (N/kg)	1.89 ± 0.25	F CON MAX (N/kg)	2.17 ± 0.16
P POWER ECC (W/kg)	-10.23.68 ±4.31	A POWER ECC (W/kg)	-8.12 ± 3.17
AM Force (BW)	1.91 ± 0.14	A POWER CON (W/kg)	25.63± 6.68
RFD MAX ECC (N/m$_s$)	75.90 ± 38.07	RFD MAX CON (N/m$_s$)	76.64 ± 20.13
F MAX L (N/kg)	3.37 ± 0.88	LR MAX (BW/S)	46.91 ± 24.27
F MIN L (N/kg)	0.63 ± 0.13	LR MAX-MIN (BW/S)	4.96 ± 2.25
IMPULSE (N/S)	0.36 ± 0.03		

* 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); RFD Maximum Concentric (RFD_{MAXCON}); RFD Maximum Eccentric (RFD MAX ECC); Average RFD Concentric ($ARFD_{CON}$); Average RFD Eccentric ($ARFD_{ECC}$); Peak RFD Concentric ($PRFD_{CON}$); Peak RFD Eccentric ($PRFD_{ECC}$); Impulse (I); Maximum Landing Force (F_{max_L}); Minimum Landing Force (F_{min_L}); Maximum Loading Rate ($L\ R_{max}$); Maximum to Minimum Loading Rate (LR MAX-MIN); Am Force = Amortization Force.

The linear stepwise regression coefficient between amortization force and other kinetic variables during jumping and landing in participants is listed in Table 2.

Table 2. Stepwise Regression coefficient between Amortization Force and other kinetic variables during jumping and landing

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	Beta	Std. Error	Beta		
Constant	118.71	4.96		23.92	0.000*
PRFD $_{ECC}$ (N/m_s)	-2.81	0.67	-0.73	-4.18	0.010*

[*] Peak RFD Eccentric (P $_{RFD\ ECC}$)

Regression models for each category of the data set, including amortization force and other kinetic variables equation 1 were calculated using equation 2:

Amortization Force (BW) = 118.71 – 2.81 × PRFD ECC

Equation 2.

Results showed a significant relationship between PRFD ECC and other kinetic variables in the first step of stepwise regression models ($p<0.05$; Table 2). But AM F and other variables haven't shown any significant relationship, and they were excluded from the analysis (Table 3).

Table 3. Excluded variables in Stepwise Regression coefficient between Amortization Force and other kinetic variables during jumping and landing

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
ARFD $_{ECC}$ (N/m_s)	-0.06[a]	-0.24	0.81	-0.06	0.41
ARFD $_{CON}$ (N/m_s)	-0.04[a]	-0.19	0.85	-0.05	0.50
PRFD $_{CON}$ (N/m_s)	-0.21[a]	-1.23	0.23	-0.31	0.99
$F_{ECC\ MAX}$ (N/kg)	-0.21[a]	-.741	0.47	-0.19	0.39
$F_{CON\ MAX}$ (N/kg)	0.00[a]	0.03	0.97	0.01	0.71
P $power_{Ecc}$ (W/kg)	-0.15[a]	-0.80	0.43	-0.21	0.86
P Power $_{CON}$ (W/kg)	.012[a]	0.68	0.50	0.17	0.99
A Power $_{ECC}$ (W/kg)	-0.14[a]	-0.76	0.45	-0.20	0.92
A Power $_{CON}$ (W/kg)	0.12[a]	0.70	0.49	0.18	0.96
RFD $_{MAX\ ECC}$ (N/m_s)	0.14[a]	0.57	0.57	0.15	0.48
RFD $_{MAX\ CON}$ (N/m_s)	0.13[a]	0.60	0.55	0.15	0.66
F $_{max\ L}$ (N/kg)	0.19[a]	1.091	0.29	0.28	0.99

L R max (BW/S)	0.19[a]	1.104	0.28	0.28	1.00
F min L (N/kg)	-0.25[a]	-1.463	0.16	-0.36	0.97
LR MAX-MIN (BW/S)	0.32[a]	1.772	0.09	0.42	0.80
I (N/s)	0.22[a]	1.239	0.23	0.31	0.92

a. Predictors in the Model: (Constant), P RFD ECC

b. Dependent Variable: Am $_{Force}$

* 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 (P Power $_{CON}$); RFD Maximum Concentric (RFD_{MAXCON}); RFD Maximum Eccentric (RFD_{MAXECC}); Average RFD Concentric ($ARFD_{CON}$); Average RFD Eccentric ($ARFD_{ECC}$); Peak RFD Concentric ($PRFD_{CON}$); Impulse (I); Maximum Landing Force (F $_{max\ L}$); Minimum Landing Force (F $_{min\ L}$); Maximum Loading Rate (L R $_{max}$); Maximum to Minimum Loading Rate (LR $_{MAX-MIN}$); Amortization Force= (Am $_{Force}$)

Discussion

The purpose of this study was to investigate the relationships between Amortization force and kinetic variables during jumping and landing based on the regression method. The results of the analysis of countermovement jump force-time phase characteristics identified that the inter-relationships between derived parameters may have a key role in assessing the performance of the jumping and landing technique in volleyball. Coaches and sports scientists need to understand the CMJ force-time curve and its extractions [3]. Force-time characteristics of CMJ are globally referenced as the main descriptors of athletic jump performance, particularly for volleyball players [52]. Athletes who participate in sports that require jumping have recorded significantly greater power during squat jumps [46, 47]. Previous literature has indicated that RFD and power development are two of the most influential fitness characteristics that can be developed [36-39].

There are variations in methods for calculating the eccentric rate of force development (RFD) during countermovement jumps in the present study. The difference between RFD Ecce may reveal unique information on eccentric force production [5]. A previous study on CMJ's calculating eccentric RFD from countermovement initiation to end reported values of 32.93 ± 16.02 N/kg/s [19]. Results from this study are comparable to the amortization and eccentric RFD outcomes reported in this and other previous research [19-¬21]. Several studies, however, have failed to find such a strong link between ECC-RFD and vertical jumping performance [41-45]. Studies found that neither eccentric nor concentric impulse had a significant correlation with CMJ height among volleyball players [46, 50].

In addition to unknown muscle fascicle lengths in vivo, the length-tension relationship of muscle does not represent all sources of elastic strain energy in the system [46]. Such alterations in these mechanical variables have been reported previously [22-25] and form the basis of the inverse linear relationship between force and velocity measured through loaded squat jumps. Connective tissue in muscle includes predominantly Titin (a protein in humans) and fascia surrounding contractile elements, both of which are mediated by calcium to suggest voluntary control of elastic stiffness [26]. In addition, tendon and bone contribute strain energy to the system and may absorb strain energy more effectively [46] this is a reasonable conclusion in vivo with a recent investigation reporting faster movements induced greater tendon strain [27], and the evidence reporting increased joint loading with stiffer landings [28-30]. In stiff stretch-shortening cycle movements such as running, the tendon buffers energy by lengthening. During muscle-tendon unit lengthening, the muscle is afforded greater time and lesser displacement to disperse forces and reduce work [31, 32]. Increments in peak power measures, which are linearly related to force and velocity measures, also facilitate higher jump heights because larger numbers of muscle fibers contract in a relatively short time [47-49]. Features of the force-time curve have been found to appear after power-focused training [47]. This interaction between muscle and tendon effectively allows strain to be dispersed towards more resilient tissues than muscle [32]. Therefore, fast movements utilizing a stretch-shortening cycle appear to strain connective tissue throughout the system more than the contractile elements of muscle alone [27, 31-33]. The stretching phase is speculated to reflect the jumper's ability to transition to concentric action as well as the stretch experienced by the musculotendinous unit after the countermovement [51].

The vertical jump performance (cm) was determined using the vertical velocity of the center of mass at takeoff calculated by integrating the vertical GRF through the impulse-momentum method [34] (figure 1). According to Newton's law, the higher the jump, the greater the kinetic energy which should be absorbed correctly to prevent injury [35]. The data from this study may suggest that conditioning coaches could identify a player's preferred position and incorporate a specific training program to enhance the player's power. However, future research is warranted to elucidate the exact mechanisms influencing characteristics of the stretching phase as well as its role in jump performance.

This study only measured the CMJ among volleyball players. Therefore, the ability to generalize our results to other athletes is limited by the range of jump heights observed in our study. Participants were instructed to begin CMJ with a preliminary downward movement by flexing at the knees and hips (eccentric phase) and then the knees and hips were immediately extended again to jump vertically (concentric phase), while the hands moved upward and extended above the head. Some participants may not have been accustomed to this cue and technique, having entered the study with different jumping experiences despite all participants being in routine volleyball training for three sessions a week.

Conclusion

In conclusion, the jump correlated to the peak rate of force development variable derived from the eccentric phase only. This study only assessed the CMJ-derived kinetics variables in separated phases of jumping and landing with amortization in a jump test. Movement utilization of the stretch-shortening cycle in the eccentric phase may provide a strong assessment tool for coaches to help athletes reduce injury, improve performance, and monitor fatigue.

Ethical Considerations:

Compliance with ethical guidelines

This study was approved by the Research Ethics Committee of the Sport Sciences Research Institute of Iran (code: IR.SSRI.REC.1151).

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The authors state no funding is involved.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

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روابط بین نیروی آمورتیزیشن و متغیرهای کینتیک در حین پرش و فرود

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چکیده

هدف: متغیرهای منحنی نیرو-زمان پرش، برای ارزیابی ویژگی‌های عصبی عضلانی و بیومکانیکی مرتبط با پویایی اندام تحتانی استفاده می‌شوند. مرحله آمورتیزیشن بین فعالیت عضلانی اکسنتریک و کانسنتریک رخ می دهد و به عملکرد در حین پرش و فعالیت های چابکی مربوط می شود. این مطالعه رابطه بین نیروی آمورتیزیشن و متغیرهای کینتیک را در حین کار پرش و فرود تعیین می‌کند.

روش شناسی: ۱۷ والیبالیست مرد حرفه‌ای نوجوان، سه پرش انجام دادند. عملکرد چرخه کشش - انقباض پاها در مورد حرکت پرش بر روی صفحه نیرو (Kistler, CH) ارزیابی و داده‌های کینتیک از متغیرهای منحنی نیرو - زمان در نرم‌افزار متلب محاسبه شد. برای برآورد رابطه بین نیروی آمورتیزیشن و سایر متغیرها در حین پرش و فرود و همچنین ضریب همبستگی هر متغیر از تحلیل رگرسیون گام به گام چندگانه استفاده شد.

نتایج: رابطه معنی‌داری بین نیروی آمورتیزیشن و سایر متغیرها در گام اول مدل‌های رگرسیون گام به گام مشاهده شد.

نتیجه گیری: این داده ها ممکن است نشان دهد که مربیان باید موقعیت های بازیکنان خود را شناسایی کنند و یک برنامه تمرینی خاص را برای افزایش قدرت بازیکنان ترتیب دهند.

واژه‌های کلیدی

پرش، فاز آمورتیزیشن، فاز اکسنتریک، فاز کانسنتریک، مرکز جرم، ، منحنی نیرو-زمان

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