VERTICAL JUMP HEIGHT PREDICTION THROUGH THE ANALYSIS OF GROUND REACTION FORCES

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This study aimed to perform a linear multivariate regression analysis of kinetics variables to predict the height obtained in the countermovement jump (CMJ). Twenty-nine men, physically active, performed 3 maximum CMJ with 1 minute of interval between each jump. Variables of force and velocity, such as peak force in the eccentric phase (r=0.405), peak velocity in the concentric phase (r=0.393), and peak of force (r=0.392), showed positive association with the jump height. The regression analysis showed that the combination of the variables explained 65% of the jump height, it also demonstrated that force and velocity are determinant for the performance of this task.

KEY WORDS: countermovement jump, regression, eccentric, concentric

INTRODUCTION: The vertical jump (VJ) is a motor skill very useful on training purposes and on the assessment of lower limbs strength and power in sports (Andrade, Amadio, Serrão, Kiss, & Moreira, 2012; Gomes, Pereira, Freitas, & Barela, 2009). The assessment of VJ provides many kinetics and kinematics variables that can be utilized on training program in order to improve performance (Mandic, Jakovljevic, & Jaric, 2014). The Countermovement Jump (CMJ) is a type of VJ that consists in an eccentric phase followed by a concentric phase that allow the stretch-shortening cycle to optimize muscle contraction (Ugrinowitsch & Barbanti, 1998). This characteristic provides greater strength compared to others types of vertical jump, due to the reutilization of elastic energy (Bobbert, Gerritsen, Litjens, & Van Soest, 1996).
The generated strength can be analyzed during the performance of the CMJ on the force plate. In addition, kinetics variables obtained from ground reaction force can help in the interpretation and understanding of the performance of this motor skill (Andrade et al., 2012; Gomes et al., 2009; Dal Pupo, Detanico, & Santos, 2012). Andrade et al. (2012) found that temporal parameters contribute more to jumping performance. On other hand, Downling and Vamos (1993) claimed that peak power is a good predictor of performance. Therefore, little is known about what kinetics variables have more influence on the vertical jump height. Thus, a multivariate analysis can identify the main measures for the assessment of vertical jump. The aim of the present study was to perform a linear multivariate regression analysis of kinetics variables to predict the height obtained in the CMJ. The study has the potential to provide more information about the assessment of vertical jump helping coaches, players and professional of sports to identify the main kinetic parameters related to the CMJ height.

METHODS: Participated in the study 29 men (all physically active, selected by convenience, free of neuromuscular diseases, mean age=21.09±2.45 years old and body mass=73.93±8.96 kg). All subjects signed a term of voluntary participation in the study. Firstly, one experimental session was performed, in which the individuals executed dynamic stretching and 7 CMJ as a warm-up, followed by 6 submaximal and 1 maximum CMJ, with 15 seconds of interval between each jump. After the warm-up, it was adopted 3 minutes of interval to perform 3 more maximum CMJ with 1 minute of interval between them. During the test, the subjects were encouraged to perform their best jump height. Subjects received feedback about their jump height after each trial. During the eccentric phase, the individuals were instructed to flex their knees in 90 degrees and to avoid flexing them during the flight phase. Subjects were also instructed to land on the force plate area. The force plate (AMTI OR6-7-2000; 46,4cm x 50,8cm x 8,25cm; sampled at 200Hz) registered the ground reaction forces of the CMJ.

The jump height (measured according to Linthorne (2001), see figure 1) was used as a dependent variable to be predicted through a linear regression analyzes by the following independent variables: (1) time to the peak of negative velocity; (2) time of the eccentric phase; (3) time to perform the jump; (4) time of the concentric phase; (5) peak force in the concentric phase; (6) time to peak force in the concentric phase; (7) lower ground reaction force; (8) peak of the negative velocity; (9) peak force in the eccentric phase; (10) peak velocity in the concentric phase, and (11) velocity at the beginning of the flight phase. The output signal of the force plate was filtered at 30Hz (recursive *Butterworth* Filter, 2º order). The processing analysis was performed through a routine in *Excel* 2010. The best jump height was used for the analysis. Descriptive statistics was represented by mean (*M*) and standard deviation (*SD*). Associative analysis was performed by a linear multivariate regression analysis. Statistical significance was set at 5% (P<0,05).

$$v_{to} = \frac{g t_{flight}}{2} \qquad y_{flight} = \frac{v_{to}^2}{2g}$$

Figure 1. Equation adopted to measure jump height (Linthorne, 2001).

Legend: v_{to}= vertical velocity takeoff, g= gravity aceleration, t_{flight}= flight time, y_{flight}= jump height.

RESULTS AND DISCUSSION: The mean and standard deviation of each variable are showed in table 1. One example of the kinetic data of vertical jump was showed in figure 2.

Table 1
Mean and Standard Deviation (*SD*) of each variable in CMJ

Variables	Mean±*SD*
1-Jump Height (cm)	40±6,13
2-Time to the peak of negative velocity (s)	0.30±0.16
3-Time of the eccentric phase (s)	0.53±0.24
4-Time to perform the jump (s)	0.95±0.24
5-Time of the concentric phase (s)	0.42±0.38
6-Peak force in the concentric phase (N)	1636.04±522.97
7-Time to peak force in the concentric phase (s)	0.57±0.26
8-Lower ground reaction force (N)	364.98±203.21
9-Peak of the negative velocity (m/s)	0.50±0.40
10-Peak force in the eccentric phase (N)	1610.85±546.13
11-Peak velocity in the concentric phase (m/s)	1.88±0.9
12-Velocity at the beginning of the flight phase (m/s)	0.38±0.07

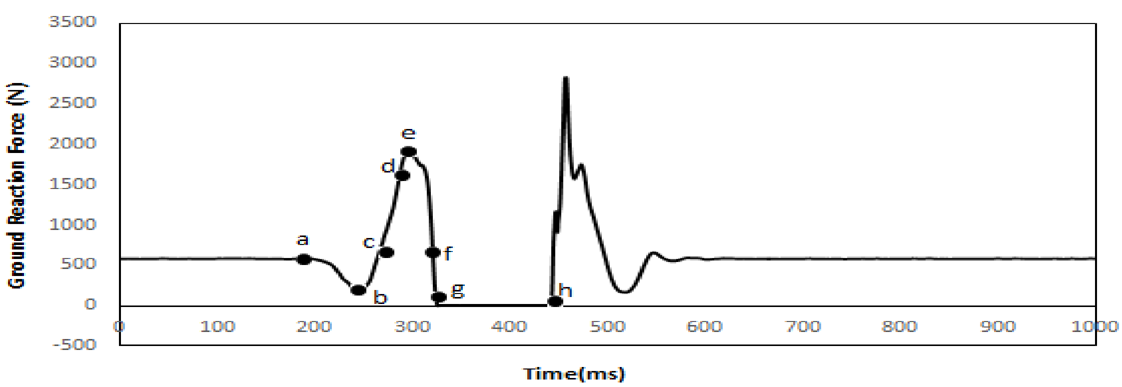

Figure 2. Kinetic data of the vertical jump.

Legend: a= start of the jump, a-c= time to the peak of negative velocity, a-d=time of the eccentric phase, a-h= time to perform the jump, b=lower ground reaction force, c=peak of the negative velocity, d=peak force in the eccentric phase, d-g=time of the concentric phase, e=peak force in the concentric phase, d-e=time to peak force in the concentric phase, f= peak velocity in the concentric phase, g=velocity at the beginning of the flight phase, h= landing.

The jump height showed positive association with peak force in the eccentric phase (*r*=0.405; *M*=1610.85±546.13N), peak velocity in the concentric phase (*r*=0.393; *M*=1.88±0.9m/s), and peak of force in the concentric phase (*r*=0.392; *M*=1636.0±522.9N). The positive association of peak force also was found in the study of Dal Pupo et al. (2012). Such results indicate that force and velocity are important for the development of power. According to Maulder, Bradshaw and Keogh (2006), the average power is the variable that showed the greater correlation with the 10 meters sprint performance of track sprinters in comparison with other measures of CMJ, Squat Jump, Continuous Jump, Single Leg Hop for Distance and Single Leg Triple Hop for Distance. In fact, the CMJ is often used as feature to access lower limb power (Ugrinowitsch, Barbanti, Gonçalves, & Peres, 2000).
Negative association was found between jump height and lower ground reaction force (*r*=-0.411; *M*=364.9±203.2N), time to perform the jump (*r*=-0.383; *M*=0.95±0.24s), and time of the concentric phase (*r*=-0.364; *M*=0.42±0.38s). Apparently, the lower the squat the slower would be the jump height. The results of the present study corroborate with the study of Andrade et al. (2012). These authors claim that temporal parameters (passive peak force, time to passive peak force, load rate, time in the eccentric phase, and time to peak of propulsion force) contribute significantly to the vertical jump performance in female basketball players. In addition, a faster concentric phase seemed to provide a better utilization of stretch-shortening cycle. According to Bobbert et al. (1996), the reutilization of elastic energy in the concentric phase assists in the increasing of the jump height in the CMJ, compared to Squat Jump. Indeed, Anderson and Pandy (1993) showed that in this type of jump, more gravitational potential energy of the skeleton is converted into elastic energy in comparison with the Squat Jump. The table 2 showed the correlations of each variable independent with the jump height.

Table 2
Correlation of each variable independent with the jump height in CMJ

Variables	Correlation
1-Time to the peak of negative velocity (s)	0.27
2-Time of the eccentric phase (s)	0.18
3-Time to perform the jump (s)	-0.38*
4-Time of the concentric phase (s)	-0.36*
5-Peak force in the concentric phase (N)	0.39*
6-Time to peak force in the concentric phase (s)	0.05
7-Lower ground reaction force (N)	-0.41*
8-Peak of the negative velocity (m/s)	0.26
9-Peak force in the eccentric phase (N)	0.40*
10-Peak velocity in the concentric phase (m/s)	0.39*
11-Velocity at the beginning of the flight phase (m/s)	0.24

*$P<0.05$

Regression analysis showed association between the jump height and the linear combination of the independents variables (*r*=0.808; R^2=0.653; *P*=0.01). Approximately 65% of jump height performance could be explained by the kinetic variables selected. The other 35% was explained by others factors, such as: coordination, practice time, training status, and kinematics variables.
Despite of the individuals were familiarized with the task and were classified as physically active, an inter-variability was verified in the performance of the subjects. The greatest variations of mean in the variables of the study did not show association, or showed a negative association, with the jump height. This result was explained by the fact that practice time (experience) was not controlled. Other factor that can explain the inter-variability between subjects is their own CMJ coordination. Even though, the subjects received the same instruction to perform the task, a kinematic analysis was not applied in the present study to ensure that the same coordination was used between subjects. According to Bobbert, Richard Casius, Sijpkens and Jaspers (2008), humans have some degree of variance to perform the jump.

CONCLUSION: The linear combination of the kinetic variables analyzed was able to explain about 65% of the height performed in the CMJ. Other factors such as training status, coordination, practice time, and kinematics variables, were suggested as components for the other 35% of performance. The great generation of force and velocity, combined to a properly reutilization of elastic energy seems to provide substantial effect on the performance of the CMJ. It was suggested the use of exercises that provide the generation of great force and velocity with the reutilization of elastic energy, such as plyometric exercise, to improve the performance on CMJ.

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