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ORIGINAL

KNEE EXTENSION, THE MOST IMPORTANT FACTOR FOR CMJ EVALUATIONS IN VOLLEYBALL PLAYERS

EXTENSIÓN DE RODILLA, FACTOR MÁS IMPORTANTE DURANTE EVALUACIONES CON CMJ EN JUGADORES DE VOLEIBOL

Fábrica, G.[1]; Bermúdez, G.[2]; Silva-Pereyra, V.[3]; Alonso, R.[4]

[1] PhD. Biological Sciences. Depto. Biofísica, Facultad de Medicina, Universidad de República (Uruguay) cgfabrica@gmail.com

[2] BSc. Clinical Neurophysiology. Instituto Universitario Asociación Cristiana de Jóvenes Uruguay (Uruguay) gbermudez.neuro@gmail.com

[3] Mg. Ciencias Biológicas. Instituto Universitario Asociación Cristiana de Jóvenes, Uruguay. Depto. Biofísica, Facultad de Medicina, Universidad de República (Uruguay) vlntnslv@gmail.com

[4] Engineer. Depto. Métodos Cuantitativos, Facultad de Medicina, Universidad de República (Uruguay) alonso@fmed.edu.uy

Spanish-English translators: Juan Silva Schaich, juansich@hotmail.com

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ABSTRACT

This paper evaluates which variables, among those that are more understandable for an athlete, are predictors of jump height with countermovement (CMJ). Twelve amateur volleyball players (24.5 ± 2.7 years; 1.85 ± 0.6 m; 80.3 ± 5.2 kg; mean ± SD) participated in the study. The relationships between 15 kinematic variables and jump height were evaluated using Spearman's correlation coefficients. With a multivariate regression model, it was determined that the maximum knee extension velocity and the transition time are the independent predictors. It was concluded that the knee extension speed is the most important factor for the height of the jump. Changes within the range tolerated for knee action, could affect the evaluations based on the maximum height of the CMJ.

KEY WORDS: Vertical jump; kinematics; performance; technique.

RESUMEN

En este trabajo se evalúa cuales variables, dentro de las que resultan más entendibles para un atleta, resultan predictoras de la altura del salto con contramovimiento (CMJ). Doce jugadores de voleibol amateur (24,5 ± 2,7 años; 1,85 ± 0,6 m; 80,3 ± 5,2 kg; mean ± SD) participaron del estudio. Se evaluaron las relaciones entre 15 variables cinemáticas y la altura del salto usando el coeficiente de correlación se Spearman. Con un modelo de regresión multivariado, fue determinado que la velocidad máxima de extensión de la rodilla y el tiempo de transición durante el apoyo son predictores independientes. Se concluyó que la velocidad de extensión de rodilla es el factor más importante para la altura del salto y se observó que cambios dentro del rango tolerado para la acción de la rodilla, podrían afectar las evaluaciones basadas en la altura máxima del CMJ.

PALABRAS CLAVE: Saltos verticales; cinemática; rendimiento; técnica.

1. INTRODUCTION

The height reached in a countermovement jump (CMJ has been used for many decades to evaluate abilities in sport (Komi & Bosco, 1978; Bosco, 2007; Dal Pupo et al., 2012; Petrigna et al., 2019). Three phases are determined in the CMJ by the vertical displacement of the body mass center (COM) during the contact time with the ground. The countermovement phase when the COM drops down, followed by the transition phase and finally the push-off phase when the COM goes up (Bosco, 2007). In different approaches it is shown that the motor actions during the first two affect the push-off (Anderson & Pandy, 1993; Bobbert et al., 1996; Aboodara et al., 2013). However, the height attains is determined by the linear speed of COM at the moment of take-off (Samozino et al., 2010; Winter et al., 2016; Ruddock & Winter 2016; Ferraro & Fábrica, 2017), which depends of the angular velocity transfer of the body segments at linear velocity of the COM during push-off phase (Bobbert & van Soest, 2001). Based on this assumption, a kinematic analysis of angular variables during the push-off phase is enough to explain the height reached in a CMJ.

Many studies tried to evaluate the relative contributions of different kinetic and kinematic variables in CMJ height (Dowling & Vamos, 1993; Aragon-Vargas, 1997; Ferragut et al., 2003; González-Badillo & Marques, 2010; McErlain-Naylor et al., 2014; Johnston et al., 2015; Sánchez-Sixto et al., 2019), without still reaching a consensus regarding which variables are the most important. In addition, the variables frequently used in research, for example power and joint torque, are not too useful when giving directions to an athlete. In that sense, the duration of the phases, ranges and angular velocities of the joints are more understandable information. Regarding the importance of the duration of the phases, the bibliography shows that there is no clear response (Aragon-Vargas, 1997; Ferragut et al., 2003; González-Badillo & Marques, 2010). Moreover, although the importance of the analysis of the actions of the joints during the push-off appears clearly justified from the theoretical point of view in Bobbert & van Soest, (2001). There are different opinions regarding the contribution of the hip, knee and ankle at the height of the CMJ. Hubley & Wells (1983) established that the knee is the joint that contributes the most (49% of the total positive work), while Fukashiro and Komi (1987), highlight the contribution of the hip (51%) and Vanezis & Lees (2005) highlight the contribution of both (30% knee and 42% hip). Other works instead highlight the importance of ankle action (McErlain-Naylor et al., 2014; Johnston et al., 2015).

On the other hand, during the field evaluations, the control of the CMJ technique is performed based on maximum knee flexion and hip control during the push-off (Hébert-Losier et al., 2014; Sánchez-Sixto et al., 2019). In the case of the knee, there is a tolerance of ± 5° in maximum flexion, although this tolerance is not clearly justified (Fábrica et al., 2013; Bermúdez & Fábrica, 2014) and there is usually no control of the joint situation at the time of takeoff Therefore, it is possible that the differences results in reached height is due to changes in the action of proximal joints, instead of the differences in the capacities that are proposed evaluate through the CMJ height. Moran & Wallace (2007), found that increase 20° the range of knee resulted in a 17 % improvement in CMJ height. However, it is still necessary to discuss in greater depth the effect that small angular variations could have on the evaluations results. Identifying predictive variables of the height of the CMJ, within those that allow indications to an athlete, and know if the angular variations within the tolerance range considered can lead to different interpretations during the evaluations, is relevant information for both athletes and coaches.

2. OBJECTIVES

This study aimed first to identify the actions of the lower extremities that predict the height reached in a CMJ within a set of variables that athletes can easily recognize and interpret. In the second instance, determine if the result of the evaluation can be affected when a quantitative control of the jump technique is not carried out.

3. METHODS

Twelve male amateur volleyball players (24.5 ± 2.7 years, 1.85 ± 0.6 m, 80.3 ± 5.2 kg, mean ± SD) with more than 5 years of sports experience and a training frequency of 3 times a week, participated in this study. The sample size for this work was estimated based on the data reported in previous studies (Markovic & Jaric, 2007; Pazin et al., 2013), and in the Cohen (1988) guidelines, with an alpha level of 0.05 and a power level of 0.8. All subjects had experience in evaluations with CMJ, with no injuries suffered during the 6 months prior to this study, neither undergone any previous surgery in the lower limbs. The participants were informed about the objectives and the characteristics of the study and their consent was previously obtained. The study was conducted following the requirements stipulated in the Declaration of Helsinki 2013, the protocol and informed consent received approval from the local ethics committee (approval number 07114000176409).

The data was recorded in one day during their precompetitive period. During the records the subjects used their professional training gear. After a 10-minute self-selected warm-up and three previous submaximal jumps, participants performed five maximal CMJ trials. They were instructed to perform the jumps in the same way as in field assessments. Individuals initiated from an upright standing position and performed a countermovement, until they reached a knee flexion angle of approximately 90°, with hands at the waist during the whole movement. Only the jumps within the range of ± 5° in the knee maximum flexion were considered. Lather, the best three jumps (maximum height reached) of each subject were selected for future analysis. Forty nine reflective markers were attached to each participant, positioned over anatomical references. This number of markers allows precise reconstruction of the COM (Fábrica et al., 2019) and therefore greater precision in determining the height of the jump, which was the dependent variable in this study. Eight synchronized cameras Bonita (1 MPx optical camera, 250 fps featuring a varifocal lens (4 to 12 mm) and NIR strobe) connected to VICON MOTION SYSTEMS (Nexus 2.5) (*Oxford Metrics Ltd*) were used to obtain a 3D reconstruction of movement. Marker trajectories were smoothed using a fourth order Butterworth filter, cut-off frequency of 6 Hz without delay, and were exported to MATLAB R2017a ® (*Mathworks, Inc*.) to perform the determination of variables.

Fifteen kinematics factors (independent variables, table 1) were selected in order to analyse their association with the height reached in a CMJ (dependent variable). Before using averaged values for both limbs, it was verified that bilateral symmetry could be assumed. For this the limb symmetry indices (LSI) were calculated for each variable as: left limb/ right limb × 100. Limb symmetry deficits were defined by LSI <90%. In those variables without symmetry deficit, the average value of both members was used. The angles were considered negative if there was a plantar flexion for ankles and an extension for knees and hip.

Table 1. Explanation of analyzed variables and their corresponding abbreviations.

Abbreviation of variables	Explanation
HJ	maximum height reached in the jump, determined from the difference between the maximum value of the vertical position component of the COM and the value at the time of take-off.
Tc	countermovement phase duration
Tt	transition phase duration
Tp	push-off phase duration
Hr	averaged angular range of the hip in the sagittal plane during push-off phase.
Kr	averaged angular range of the knee in the sagittal plane during push-off phase.
Ar	averaged angular range of the ankle in the sagittal plane during push-off phase.
VHm	mean angular velocity of the hip in the sagittal plane during push-off phase.
VKm	mean angular velocity of the knee in the sagittal plane during push-off phase.
VAm	mean angular velocity of the ankle in the sagittal plane during push-off phase.
VHp	peak angular velocity of the hip in the sagittal plane during push-off phase.
VKp	peak angular velocity of the knee in the sagittal plane during push-off phase.
VAp	peak angular velocity of the ankle in the sagittal plane during push-off phase.
Htp	time of peak angular velocity of the hip, during the push-off phase.
Ktp	time of peak angular velocity of the knee, during the push-off phase.
Atp	time of peak angular velocity of the ankle, during the push-off phase.

3.1. STATISTICAL ANALYSIS

The mean and standard deviation (SD) of all variables were calculated. The intensity of the associations between kinematic variables and jump height was determined with Spearman correlation coefficients. A multivariate linear model was evaluated to predict HJ. Variables with $p < 0.10$ on the univariate model were included in the multivariate model. Stepwise backward-selection was used with a significance level of removal of 0.1, muticollinearity was evaluated with the inflation coefficient of variance (VIF). After define the final model, to assess adjusted correlation, the partial correlation was calculated for each of the predictor variables. The Breusch-Pagan and Cook-Weisberg was tested for heteroskedasticity and Shapiro-Wilks for normality. Statistical level of significance used was $\alpha = 0.05$. Data analysis was done using Stata 13 and R Softwares.

4. RESULTS

For all the variables analyzed, there was no deficit of symmetry, therefore the average value was used for both extremities for all variables related to joint angles.

The values obtained for the fifteen independent variables considered in this study and HJ are presented in Table 2, together with the corresponding correlation coefficients obtained between each variable and HJ. The correlations reflect that the HJ was correlated with; Tt, Hr, Kr, VKm, -VKp and VHm.

The results of the univariate and multivariate analysis performed are presented in Table 3. The equation obtained with the multivariate analysis model is:

$$HJ = 0.0129 + 0.0006(-VKp) - 1.6853\ Tt, \quad (R^2 = 0.65).$$

Figure 1 shows the relationship between HJ and the two independent predictors of the final model. The partial correlation between HJ and VKp (-0.73) is stronger than HJ and Tt (-0.31). The negative correlation between HJ and VKp responds to the criterion assumed for the angular extension.

Table 2. Descriptive analysis of the variables and Spearman correlation coefficient rs (n=36).

	Mean	SD	Correlation
HJ (m)	0.383	0.041	
Tc (s)	0.460	0.043	-0.22
Tt (s)	0.032	0.005	-0.51*
Tp (s)	0.266	0.022	0.07
VHp (°/s)	-509.288	34.070	-0.19
VKp (°/s)	-723.648	48.344	-0.78*
VAp (°/s)	-597.997	149.119	-0.14
Htp (s)	0.247	0.025	0.01
Ktp (s)	0.259	0.024	0.04
Atp (s)	0.26	0.025	0.04
Hr (°)	-67.713	7.103	-0.58*
Kr(°)	-72.713	9.597	-0.49*
Ar(°)	-44.946	7.591	-0.09
VHm (°/s)	-254.853	24.170	-0.55*
VKm (°/s)	-273.792	35.393	-0.42*
VAm (°/s)	-170.317	34.861	-0.05

*= p<0.05

Table 3. Result of the linear regression model (non-standardized coefficients).

Variable	Univariate	Std. Err	p-value	Multivariate*	Std. Err	p-value
Tt (s)	-3.9964	1.15058	0.001	-1.6853	0.87890	0.064
VKp (°/s)	-0.0006	0.00008	0.001	-0.0006	0.00009	0.001
Hr (°)	-0.0030	0.00079	0.001			
Kr (°)	-0.0021	0.00063	0.001			
VHm (°/s)	-0.0009	0.00024	0.001			
VKm (°/s)	-0.0005	0.00017	0.001			

* were included variables with p<0.1

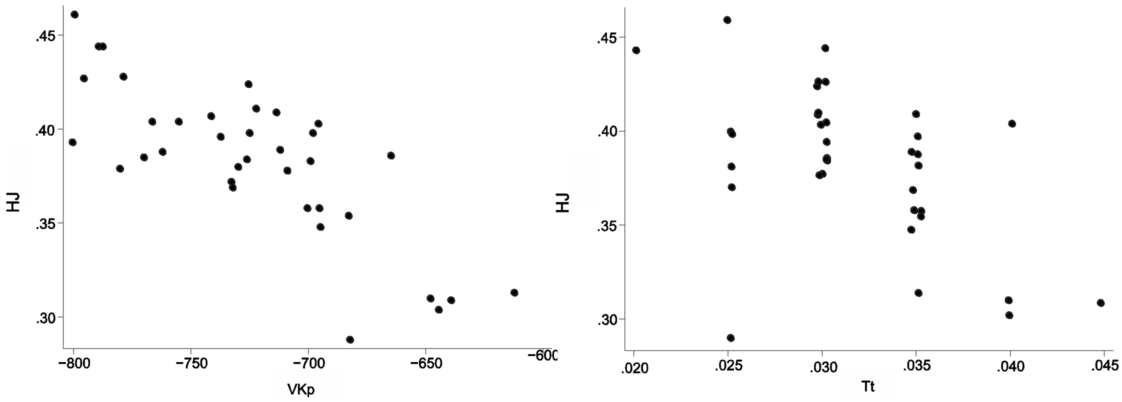

Figure 1. Relationship between countermovement jump height (HJ) and the two independent predictors found in this study: maximum knee extension speed (VKp) and time of transition phase (Tt). As previous articles indicate that Tt is an important variable, based on the fact that its significance was close to 5% and a slight improvement in the fit, we chosen to leave it in the mode.l

5. DISCUSSION

In this study, predictive variables of CMJ height were identified, within those kinematic variables that athletes can interpret. In addition, it was analyzed whether changes in the execution of the technique within the range usually tolerated could affect the evaluations based on the height of the jump. Although all the variables considered in this study have been previously analyzed in the CMJ, the specific focus as well as the main questions addressed have not been considered in previous studies.

The HJ found in this study was lower than that reported in previous works (González-Badillo & Marques, 2010; McErlain-Naylor et al., 2014, Sánchez-Sixto et al., 2019). This law value can be associated with the features of our sample. , amateur athletes who trained three times a week. In fact, the values in HJ are very close to those reported in works where non-athletes physically active subjects are analyzed (Jurado-Lavanant et al., 2017).

As for the associations found between the height and the independent variables considered a first point to highlight is that within the temporal variables only Tt correlated statistically significant with HJ. The duration of the countermovement and push-off phases did not showed statistically significant associations with height. These results are opposed to other works where the importance of counter-movement (Ferragut et al., 2003) and the thrust phase (Dowling & Vamos, 1993; Bermúdez & Fábrica, 2014) at the height of the jump is remarked. In that sense, our results are closer to what was established by González-Badillo and Marques (2010), who argued that the duration of the eccentric and concentric phases are weak indicators of the performance of the CMJ. The most important aspect to consider regarding the duration of the phases is that there is a negative correlation between Tt and HJ. This can be interpreted as a decrease in the transition time allows a better use of the shortening-stretching cycle, although in reality the partial correlation between HJ and Tt was low.

To identify the independent predictive variables of the HJ, a multivariate regression model was implemented. The variables Tt and VKp together explain 65% of the height reached. Among the angular variables that were analyzed, (VKp) was the only one that remained in the final model with HJ. The model indicates that the higher the knee extension speed, the greater the jump height. This result is consistent with Hubley and Wells (1983), who indicated that the knee contributes a high percentage (49%) to the positive mechanical work done during a CMJ. These results as well are in line with previous studies that show that the power of knee is determinant in the height of vertical jumps (Aragon-Vargas, 1997; McErlain-Naylor et al., 2014; Johnston et al., 2015). Although we do not measure joint power, the higher joint peak speed can be associated with a higher power (Young et al., 1999). However, the works of McErlain-Naylor et al., (2014) and Johnston et al., (2015) also emphasize the relevance of the ankle action as important predictors of the height of a CMJ. That the influence of the ankle action on HJ was not detected constitutes one of the most marked differences with respect to what was found in previous studies. Here again we must consider that the characteristics of the sample studied may be influencing. Although is expected that amateur and professional athletes use similar jumping techniques (Vanezis & Lees, 2005; McErlain-Naylor et al., 2014), it is possible that in expert athletes the last link in the kinematic chain contribute to a greater extent at the height of the CMJ than in amateur athletes like the ones we have studied. This difference may also be due to the fact that the reference studies (McErlain-Naylor et al., 2014; Johnston et al., 2015) use variants in the CMJ technique with respect to the jumps performed in our study. These changes in technique, for example in hands position, may be the explanation for many of the differences found (Blache & Monteil, 2013; Petrigna et al., 2019).

An important aspect that arises from this study is that a non-rigorous control of the knee can affect the result of the evaluation. Although the indication was to reach a maximum knee flexion of 90º, Kr was below that value. The Kr value can be altered both when not reaching 90 ° flexion or by greater knee flexion at takeoff. In a recent study Sánchez-Sixto et al. (2019), discuss the effect of the displacement of the COM on the differences in the height of vertical jumps and suggest the need to examine the displacement of the COM to properly interpret the differences between the SJ and the CMJ when the established criterion is 90° of knees flexion.

For its part, Moran & Wallace (2007), found that increasing the range of movement of the knee from 70º to 90º results in a 17% increase in the height of the jump. Since our values were within that range, we could assume that if the subjects had jumped closer to the expected range, the height would be close to that reported in previous work done with athletes (González-Badillo & Marques, 2010; McErlain-Naylor et al., 2014). On the other hand, the main predictor of jump height found in this work (VKp), has a strong correlation with Kr and Hr.

Based on this we can say that changes in the range of motion of these two joints could be influencing VKp, thus varying the height of the jump and therefore the interpretation that arises from this parameter. During evaluations with CMJ, athletes are instructed to restrict hip movement and achieve a 90° knee-level range. These restrictions are intended to always use the same technique. Our results indicate that the control of the technique should include a quantification of the angular range of the most proximal joints.

In summary, our results lead us to the idea that to achieve a good height in the CMJ athletes must focus mainly on two things, have a fast transition phase, which has already been discussed in previous work, and extend the knees as quickly as possible during the push-off, the latter being the most important factor. This is a result with possible practical interest in the sense that it suggests that coordination may be significantly influencing the evaluation of physical abilities through the height of the CM. In addition, the results of our study suggest that the control of the CMJ technique should be stringent and include angular range quantifications, failure to do so may lead to a wrong interpretation of the capacities evaluated with the CMJ. We believe that this calls into question, or at least warns about the real usefulness of many evaluation systems that do not allow to quantitatively control the angular values during the jump. It is possible that the evaluation of force manifestation through CMJ depends on those subtle technique differences and given the enormous amount of associations established between the height reached in a CMJ and different capacities, this issue should be analyzed in greater depth. It would be interesting, among other things, to extend this type of study to other populations and look for tools that better explain the relationship between joint coordination and jump height.

6. CONCLUSIONS

The height reached in a CMJ in amateur volleyball players depends mainly of the speed with which the knee is extended during the time of contact with the floor.

The use of the CMJ height as an evaluation tool without quantitative control of the technique should be reconsidered.

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