Relationship between kinetic and kinematic variables of squat jump in professional male soccer players

Relación entre las variables cinéticas y cinemáticas del salto en cuclillas en futbolistas profesionales masculinos

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Abstract

Objective: To determine the relationship between the kinetic and kinematic variables of the squat jump (SJ). Methods: A total of 13 adult male professional soccer players (age = 24.8 ± 4.5 years; body mass = 76.1 ± 6.8 kg; height = 1.77 ± 0.08 m; 6.3 ± 4.1 years of experience) were evaluated. Two PASCO PS-2142 force plates were used to measure SJ variables. Correlations coefficients (Spearman's Rho) were performed for analyze the relationship between variables. The variables analyzed were Jump height (JH), jump time (JT), Peak force absolute and normalized (PF and PF_N), time to peak force (TPF), peak rate of force development absolute and normalized (PRFD and $PRFD_N$) and time to peak RFD (TRFD).
Results: A moderate negative correlation was found between JH with TPY. Strong to very strong correlations were found between JT with TPF, PF_N, PY and $PRFD_N$.
Conclusion: In conclusion, our study of jump performance in professional soccer players revealed valuable insights into the relationships between various SJ variables. So, coaches and researchers should look other variables how JT for assess this capacity since, from a practical point of view, two subjects could obtain the same JH, but one, it could take less time (i.e., shorter JT) to apply force to reach the same JH than other, this within the field in some sports, could determine the winner in some crucial actions. These findings contribute to understanding the factors influencing jump performance in soccer players, potentially informing training, and conditioning strategies to optimize their RFD and athletic capabilities.

Keywords

Biomechanics; force plate; performance; vertical jump.

Resumen

Objetivo: Determinar la relación entre las variables cinéticas y cinemáticas del salto en cuclillas (SJ).
Método: Se evaluó a un total de 13 jugadores adultos de fútbol profesional masculino (edad = 24,8 ± 4,5 años; masa corporal = 76,1 ± 6,8 kg; altura = 1,77 ± 0,08 m; 6,3 ± 4,1 años de experiencia). Se utilizaron dos placas de fuerza PASCO PS-2142 para medir las variables de SJ. Se realizaron coeficientes de correlación (Rho de Spearman) para analizar la relación entre las variables. Las variables analizadas fueron altura de salto (JH), tiempo de salto (JT), fuerza pico absoluta y normalizada (PF y PF_N), tiempo hasta fuerza pico (TPF), tasa de desarrollo de fuerza pico absoluta y normalizada (PRFD y $PRFD_N$) y tiempo hasta RFD pico (TRFD).
Resultados: Se encontró una correlación negativa moderada entre JH con TPY. Se encontraron correlaciones de fuertes a muy fuertes entre JT con TPF, PF_N, PY y $PRFD_N$.
Conclusiones: En conclusión, nuestro estudio del rendimiento de salto en futbolistas profesionales reveló valiosos conocimientos sobre las relaciones entre diversas variables de SJ. Así, entrenadores e investigadores deberían buscar otras variables como el JT para evaluar esta capacidad ya que, desde un punto de vista práctico, dos sujetos podrían obtener el mismo JH, pero uno, podría tardar menos tiempo (es decir, JT más corto) en aplicar fuerza para alcanzar el mismo JH que otro, esto dentro del campo en algunos deportes, podría determinar el ganador en algunas acciones cruciales. Estos hallazgos contribuyen a la comprensión de los factores que influyen en el rendimiento de salto en jugadores de fútbol, potencialmente informando el entrenamiento, y las estrategias de acondicionamiento para optimizar su RFD y capacidades atléticas.

Palabras clave

Biomecánica; salto vertical; placa de fuerza; rendimiento.

Introduction

Soccer matches require players to perform multiple and unpredictable rapid actions such as jumping, sprinting and changes of direction (Dolci et al., 2020), while some of such exertions precede crucial actions in the match such as goals (Faude et al., 2012). Therefore, optimizing these activities and identifying factors that influence their development contribute greatly to the planning and orientation of training loads (Pérez-Contreras et al., 2021). These sports actions present a limited time window for force application, so being able to apply more force in a period like that demanded by the sport action could be crucial for performance improvement (Maffiuletti et al., 2016). The ability to produce force in short periods of time is important, and normally called rate of force development (RFD), which derives from the first slope of the force-time curve recorded during voluntary explosive contractions or first-time derivative of force over time (Δforce/Δtime) (Maffiuletti et al., 2016) and two phases are distinguished, the first called the early RFD phase (<100 ms), which is predominantly influenced by muscle activation mechanisms; while the second, called late phase (>100 ms), influences to a greater extent the intrinsic properties of the muscle and its capacity for maximal force production (Cossich & Maffiuletti, 2020; Maffiuletti et al., 2016). However, this was assessed during isometric contractions, so the same influence on dynamic contractions cannot be assumed (Van Hooren et al., 2022).

Vertical jump (VJ) has been used to measure athletes' lower limb power since it is an easy test to implement, non-invasive and does not lead athletes to fatigue (Lombard et al., 2020). Among the VJ variables, the most used is the jump height (JH) due to its easy estimation and its relationship with action determinants in sports such as strength, speed, and agility (Merino-Muñoz et al., 2021; Nuzzo et al., 2008; Villaseca-Vicuña et al., 2021). However, the use of JH as an indicator of rapid force production (i.e. RFD) (Harry et al., 2021; Merino-Muñoz et al., 2020) or to assess changes in neuromuscular state such as fatigue (Gathercole et al., 2015; Lombard et al., 2020) seems to be not sensibly in some cases. This is due to the, where athletes can alter their movement strategies and maintain their performance, in this case, alter force application in the phases of jump and maintain the JH (Balloch, 2018; Schmitz et al., 2014), where another mechanical variables of VJ has been more sensible for detecting changes in the neuromuscular status of athletes (Cohen et al., 2021; Gathercole et al., 2015; Merino-Muñoz et al., 2022).

Several studies have analyzed the relationship between JH and RFD in the descent phase in countermovement jumping (CMJ), finding no associations between these variables (Araya-Ibacache et al., 2022; Barker et al., 2018; Harry et al., 2021; Merino-Muñoz et al., 2020). However, Mclellan et al. (2011) and Laffaye et al. (2014) found a moderate correlation between RFD and JH in the CMJ, but with free arm movement. Regarding the squat jump (SJ), only two studies sought this association from a 30 ms time window, and no significant correlation was found (dal Pupo et al., 2012), while other study analyzed the correlation only with peak RFD finding trivial to small correlations with JH (Van Hooren et al., 2022). Thus, the present investigation aims to determine the relationship between kinetic and kinematic variables of SJ. It is hypothesized that, as demonstrated in CMJ no relationships should be found between JH in SJ and RFD.

Method

Participants

A total of 13 male professional soccer players were evaluated, all belonging to a Chilean first-division B team (age = 24.8 ± 4.5 years; body mass = 76.1 ± 6.8 kg; height = 1.77 ± 0.08 m; 6.3 ± 4.1 years of experience). All participants were informed about the purpose and voluntary nature of the study, in accordance with the Declaration of Helsinki (World Medical Association, 2013). The assessments performed were part of the team's regular performance monitoring procedures and were conducted without any intervention or modification to the players' training routines. Therefore, ethical committee approval was not deemed necessary, as these evaluations fall under routine practice established by the club's internal policies (Winter & Maughan, 2009).

Procedure

Data collection was performed during a competitive period in 2019 at 9:30 AM before regular training (three days before the match). All subjects performed evaluations with running shoes in the club center training. The subjects' height was evaluated by a professional with ISAK II certification, with a mechanical Dry Wall Sizer 216 measuring rod. The weight was recorded using a force plate (PASCO PS-2142) while the subjects maintained their hands on their hips, looking straight ahead for 2 seconds. The data recorded were averaged to obtain body weight (Newton) and divided by gravity (-9.81 m/s^2) to obtain the body mass (kg).

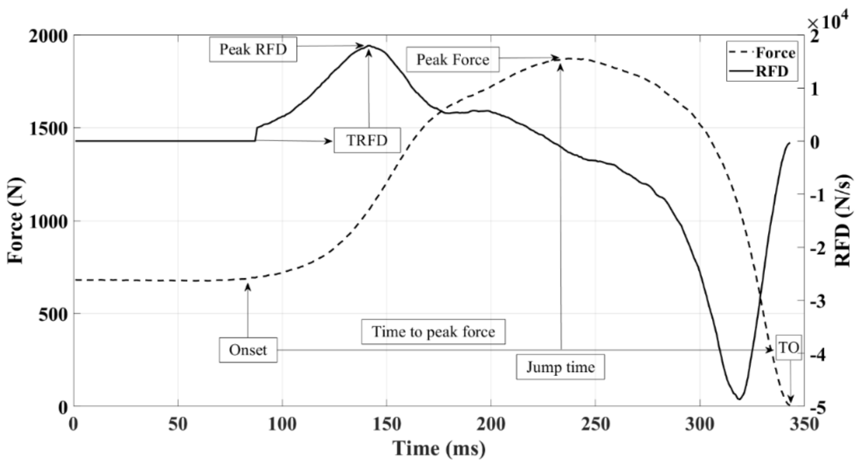
The SJ was performed on two PASCO PS-2142 force plates with a sample frequency of 1000 Herzt (Peterson Silveira et al., 2017). Before the evaluation, a standard warm-up was divided into three sets: a general set, which consisted of joint mobility exercises, dynamic stretching, and ballistic stretching emphasizing the lower extremities. This was followed by a specific set where exercises on a coordination ladder were used, performing two series of three repetitions, multi jump on 15cm hurdles, 2 series of 3 repetitions. A final set consisted of SJ jumps comprising two series of two repetitions. The entire warm-up lasted approximately 10 minutes. A jumping technique familiarization session was performed the week before the evaluations.

For the evaluation, the subjects were instructed to remain with their hands on their hips throughout the entire jump. They were instructed to lower to a position with the knee at approximately 90°, and after a countdown of 3,2,1, the tester gave a "go" command. They were previously instructed to at the "go" they should jump as fast (up) and hard as possible. If, during the jump, the subjects detached their hands from their hips or performed a countermovement, that attempt was discharged from further statistical analysis. The presence of countermovement was inspected from the force-time curve by the evaluator. The attempt with the maximal JH was used in the analysis.

Signal processing

All jumps' signals were analyzed in MatLab 2019b (Mathworks Inc., USA). Signals were low-pass functions of MatLab filtered with a cut-off frequency of 50 Hz. The jump onset was calculated using the 5 standard deviations method. The take-off and landing were defined by the first value lower than 20 N and higher than 20 N, respectively. The following variables were calculated, some of which were normalized by subjects' body weight: jump height (JH) calculated from the flight time; Jump time (JT); Peak power (PP); Time to peak force (TPF); Peak RFD (calculated every 1 ms) (PRFD); Time to peak RFD (TRFD). The variables PF and PRFD were normalized by body mass (PFN and PYN respectively). The determination of the variables is shown in Figure 1.

Figure 1. Force and Rate of force development (FRD) curves of squat jump. PF peak force; TPF time to peak force; JT jumpt time; TO take-off; TRFD time to peak RFD.



Data analysis

The distribution of the variables was analyzed using the Shapiro-Wilk test, where a distribution non normal was assumed. The coefficient of variation was calculated for analyzing the absolute reliability of variables expressed how percentage and considered values above 10 % not acceptable for sport evaluations (Turner et al., 2015). To examine the strength of the relationships between variables, Spearman's correlation coefficient (rho) values were considered trivial (0.00-0.09), weak (0.10-0.39), moderate (0.40-0.69), strong (0.70-0.89) and very strong (0.90-1.00) as were negative values (Schober & Schwarte, 2018). Equation of lineal regression was presented in graph in very strong correlation (rho > 0.9 and $r^2 > 0.8$). All statistics were conducted in IBM SPSS Statistics for (Windows), version 25.0. Armonk, NY, USA: IBM Corp.

Results

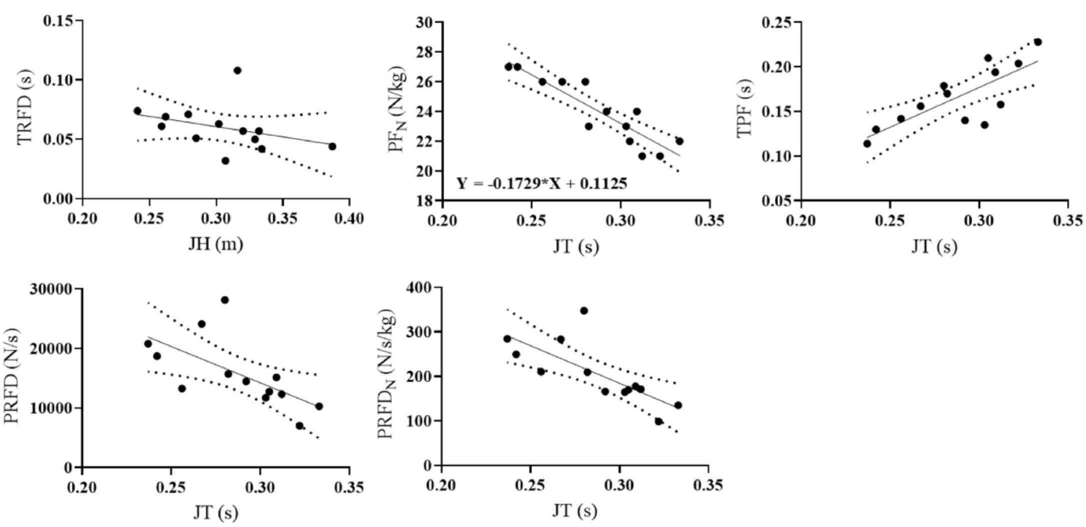
Table 1 shows the descriptive statistics of all the variables' best attempt (JH) and the correlations between the jump variables. A moderate negative correlation was found between JH with TPY. Strong to very strong correlations were found between JT with TPF, PF_N, PY and $PRFD_N$. In figure 2 the statistical significance correlations are graphed.

Table 1. Descriptive statistics of SJ variables and correlations.

			Jump height		Jump Time	
Variables	M	±SD	rho	p	rho	p
Jump height (m)	0.30	0.04	-	-	-	-
Jump time (s)	0.29	0.03	-0.01	0.97	-	-
Peak force (N)	1828	250	0.21	0.48	-0.48	0.10
Peak force normalized (N/kg)	24.0	2.20	0.03	0.94	-0.91	<0.01
Time to peak force (s)	0.17	0.03	0.20	0.52	0.76	<0.01
Peak yank (N/s)	15721	5840	0.09	0.76	-0.78	<0.01
Peak yank normalized (N/s/kg)	205	69.1	-0.02	0.96	-0.82	<0.01
Time to peak RFD (s)	0.06	0.02	-0.62	0.02	0.17	0.58

M mean; SD standard deviation; RFD rate of force development.

Figure 2. Dispersion graph between SJ variables (only significant correlations).



Discussion

The present investigation used the squat jump test to analyze the relationship between JH based on flight time and different variables derived from the force-time curve. The main findings of this study were a moderate correlation between JH with TRFD and a strong to very strong correlation between JT with TPF, PF and PRFD. Regarding the relationship between JT and the variables of the force-time curve, our results show strong to very strong correlations between them. However, contrary to our hypothesis, the JH did show a relationship with the TRFD, which could indicate that the JH would depend more on the time in which the RFD peak is reached, rather than on the RFD value itself.

Regarding the relationship between JH and SJ variables, Thomas et al. (2015), reports that JH is unrelated to variables such as PF and PP normalized to body weight. Along the same line, the study by dal Pupo et al. (2012), also found no relationships between JH and RFD, absolute PF and TPF, however, relationships were found between JH and normalized PF, but unlike ours, it was by body weight allometrically (body mass0.67). Also, the method of Samozino et al. (2008) to calculate the average power during SJ includes other parameters to be estimated in conjunction with JH, so it is possible that PP also needs other variables to increase its relationship (i.e. push-off distance and body mass). On the other hand, in a model presented by Lin et al. (2019), it is shown that as RFD increases, movement time decreases, but displacement remains constant, this could explain that subjects with lower JT have higher RFD values, not affecting JH. A recent study analyzed the relationship and found trivial to weak correlations ($p<0.05$) between JH with JT ($r=-0.22$), TPF ($r=-0.11$) and PY ($r=0.20$) and moderate to very strong correlations between JT with TPF ($r=0.94$) and PY ($r=-0.63$) (Van Hooren et al., 2022).

It is worth considering that, to the authors' knowledge, the existing literature regarding this topic is quite scarce since most of the works have used the jump with countermovement to perform these analyses (Barker et al., 2018; Harry et al., 2021; Merino-Muñoz et al., 2020). Barker et al. (2018) analyzed the relationship between JT and CMJ variables; this is presented with variables of jump descent (unloading and eccentric RFD) and ascent (concentric force average). It could be explained that subjects who obtained lower JT obtained higher values of jump kinetic variables due shorter times, which could be attributed to a series of neuromuscular mechanisms such as a higher rate of motor unit discharge and recruitment (Maffiuletti et al., 2016), the stretch-shortening cycle (Van Hooren & Zolotarjova, 2017) and a shorter time to absorb muscle slack (Van Hooren & Bosch, 2016). On the other hand, the work of Harry et al. (2021), in which only correlations between JH and some variables of the concentric phase (depth in the countermovement, push-off distance, and average concentric force) were reported in CMJ, which could indicate that JH has more relationship with the jump technique and force application in the concentric phase.

Another important mechanism to analyze is the relationship between jumping performance and isometric strength. Some studies have analyzed the relationship between JH with RFD and PF during isometric testing in various muscle groups, finding different weak to moderate correlations (De Ruiter et al., 2006; Gillen et al., 2020; Kozinc & Šarabon, 2021; Laett et al., 2021). These differences may be mainly due to how the isometric force was assessed and how the kinetic variables were calculated and normalized. On the one hand, Gillen et al. (2020), found no correlations between isometric PY and JH, results like the present study. De Ruiter et al. (2006) found moderate to strong correlations between JH and 40 ms isometric RFD (IY) normalized by peak torque (PT) of knee extension (60°; 0°=full extension). Laett et al. (2021), who found moderate correlations between JH and IY in different time windows normalized to PT ($r=0.53$ to 0.60), only analyzed knee extensors, performed a 30°/s dynamic test to determine the angle at which PT occurred, then performed isometric testing at that individual angle for each subject, while Kozinc & Šarabon (2021), found weak to small to moderate correlations between JH and IY in different joints (r=0. 206 to 0.419), they performed the tests on this same muscle group at a standard angle for the whole sample (60°; 0=full extension), highlighting that not only knee joint strength is important to achieve higher JH. This agrees with Cossich & Maffiuletti (2020), where the IY was higher in the angles where the PT was higher because the PT found (60 and 75°; 0=full extension) could coincide with the PF during the SJ when the movement starts from a 90° knee flexion, thus increasing their relationship (need verification).

The study's limitations are the low sample size and the number of attempts performed affecting the statistical power and reliability of variables. Similarly, some variables present high CVs, so their reproducibility is in doubt, implying that subjects may require more familiarization sessions. Future research should calculate the JH with other methods for calculate jump height, analyze the relationship of variables of the SJ force-time curve with sports actions and physical tests (sprint, changes of direction, maximum strength), and dynamic tests used to assess monoarticular muscle function, as well as perform these analyses with other forms of normalization (muscle mass, segment length, lower limb muscle mass).

From a practical standpoint, these results suggest that certain kinetic variables derived from the squat jump—such as peak force and time to peak force—may serve as useful indicators of neuromuscular performance in athletes, especially when jump height remains unchanged. These findings can help guide strength and conditioning programs aiming to improve jump efficiency and force production timing.

Conclusions

In conclusion, our study of jump performance in professional soccer players revealed valuable insights into the relationships between various SJ variables. So, coaches and researchers should look other variables how JT for assess this capacity since, from a practical point of view, two subjects could obtain the same JH, but one, it could take less time (i.e., shorter JT) to apply force to reach the same JH than other, this within the field in some sports, could determine the winner in some crucial actions. These findings contribute to understanding the factors influencing jump performance in soccer players, potentially informing training, and conditioning strategies to optimize their RFD and athletic capabilities.

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