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Original Article

Relationship between jump height and rate of braking force development in professional soccer players.

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Abstract
Explosive force is the ability to increase force or torque as rapidly as possible during a voluntary contraction from a low level or at rest and is primarily quantified as the rate of force development (RFD). A high RFD is considered a determinant of sports performance. Vertical jump has been shown to be dependent on RFD, and this test is widely used to evaluate the explosive strength capability of the lower limbs, as it has been associated with other skills that are determinants in sport such as strength, power, speed, agility and changes of direction.**Objective**: To know the relationship between jump height (JH) and JH normalized to height subject (JHn) calculated through flight time (FT) and the rate of force development (RFD) of the eccentric braking phase. **Method:** The sample was of a total of 21 male professional soccer players, from to a first division B team in Chile (age = 24.4 ± 4.0 years; body mass = 76.4 ± 7.1 kg.; height = 1.77 ± 0.08 meters; experience = 7.0 ± 4.5 years). Vertical jump (CMJ) was evaluated using two PASCO PS-2142 force platforms. Statistical tests of association (Pearson's r) and prediction (linear regression) were performed. **Results**: No significant relationships were found between JH and JHnwith the variables for the RFD of the eccentric braking. **Conclusion**: From the results found in this study, it is possible to conclude that the jump height calculated through the flight time and normalized to the height of the subject, does not present a significant association with the rate of development of eccentric braking force and normalized to body weight, which allows recognizing that the jump height is not a direct indicator of explosive force of the lower limb.
Keywords: task performance and analysis, sport,vertical jump, biomechanics.

Introduction

Soccer is an intermittent sport, with changes in activity, involving explosive muscular actions such as jumping, sprinting, and changes in direction (Mohr et al., 2003), which are critical to competitive success in soccer players (Castagna et al., 2003). These actions, present in a large number of sports, usually have a limited range of time to be applied (from 50 to 250 milliseconds) (Andersen &Aagaard, 2006), so being able to apply more force in these time periods could be crucial to improving sports performance and this ability has been called explosive force (Rodriguez-Rosell et al., 2018). Explosive force is the ability to increase force or torque as rapidly as possible during a voluntary contraction from a low or resting level (Maffiuletti et al., 2016) and is primarily quantified as the rate of force development (RFD) (Aagaard et al., 2002). High RFD is considered a determinant of sports performance (Baker, 2001; Stone et al., 2002; Suchomel et al., 2016)) and vertical jump has been shown to be dependent on RFD (Laffaye& Wagner, 2013; Mclellan et al., 2011). During the production of force there are different physiological, neural, and muscle-contracting properties that can affect RFD (Andersen &Aagaard, 2006). These can influence the early (<100ms) and late (>100ms) phase of RFD from the onset of contraction (Andersen et al., 2010) and this time-specific adaptation highlights that strength training programs should consider sport-specific neuromuscular demands (Oliveira et al., 2013).
Countermovement Jump (CMJ) is a type of vertical jump that is considered the most useful test to evaluate athletes' neuromuscular coordination (Claudino et al., 2017) as well as biomechanical characteristics related to lower extremity dynamics such as explosive strength and muscle power (Claudino et al, 2017; Markovic et al.,

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2004), as it has been associated with other skills that are determinant in sport such as strength, power, speed, agility, and changes of direction (Lockie et al., 2011; Nuzzo et al., 2008; Yanci et al., 2014). One of the most used variables within the vertical jump is the jump height (JH), and it has been mentioned that it is a good indicator of muscle power of the lower extremities (Kobal et al., 2017; KrÖll et al., 2017), and in turn allows to assess the neuromuscular state in soccer players (Oliver et al., 2008) as well as differentiate between levels of athletes, types of sport and gender (Kobal et al., 2017; Laffaye et al., 2014). Interval RFD has also been found to be related to muscle damage and could be a sensitive marker for post-competition monitoring (Peñailillo et al., 2015) and has been mentioned as a key variable in return to sport, as typical resistance training programs would not be sufficient to restore pre-injury RFD levels (Buckthorpe& Roi, 2017).

Different phases have been identified in the CMJ: unloading, eccentric (yielding and braking or deceleration) and concentric (Image 1) (Harry et al., 2020) and from them critical information can be extracted directly from the force-time (f-t) curve, such as the time, force and variables linking the two such as RFD, momentum and power. Considering that the performance of the jump is a result of the efficiency of these mechanisms, it is expected that the height of the jump is strongly associated with the mechanical variables responsible to produce concentric and eccentric force. The CMJ evaluated on force platforms and all variables derived from the f-t curve have proven to be reliable (Lombard et al., 2017). Specifically, it seems that RFD plays an important role in activities related to the stretch-shorten cycle, such as sprinting or jumping (Laffaye& Wagner, 2013). In this sense, Barker et al., (2018) analyzed the relationship between jump height and the rate of force development of the two eccentric phases in total, finding no significant relationships between them. Mclellan et al., (2011) found moderate associations between AS and TDF, but the jump performed had arm-free movement, so it would be considered another type of jump known as abalakov jump, which tends to have better results than CMJ (Lees et al., 2004).

Various devices have been used such as contact platforms, photocells, rotational encoder, cell apps, motion capture and force platforms (Aedo-Muñoz et al., 2020; Mclellan et al., 2011), the latter being considered the gold standard in strength assessments (Moir et al., 2005). In vertical jumps such as CMJ, formulas for calculating AS based on flight time (FT) have been validated (Moir, 2008), but these have been questioned because they present systematic and random errors when numerical methods are used that do not take into account the height of the center of mass at takeoff and as a consequence, these methods, estimate a lower height and result in a loss of information that undermines the predictive validity of these methods (Chiu &Dæhlin, 2020). On the other hand, the JH has hardly been normalized to some anthropometric parameter, which makes it difficult to compare the jump performance between subjects (Rojas-Reyes et al., 2020). Therefore, knowing easy to obtain indicators such as jump height that are related to the rate of force development could be useful to monitor soccer players. Given the above, the objective of this study is to evaluate the relationship between the height of jump calculated through the time of flight and normalized to the height of the subjects (JHn) and the rate of braking force development (RFDe) and by time intervals of 0-50ms (RFD_{0-50}) and 50-100ms (RFD_{50-100}) as well as relativized to the body weight in Chilean professional soccer players ($RFDn_{0-50}$ and $RFDn_{50-100}$).

Material &Methods

Design

This research has a descriptive-correlational character through a quantitative approach. The type of design corresponds to a non-experimental, cross-sectional study.

Participants

A total of 21 male professional soccer players were evaluated, all belonging to a team in Chile's first division B (age = 24.4 ± 4.0 years; body mass = 76.4 ± 7.1; height = 1.77 ± 0.08 m; 7.0 ± 4.5 years of experience). All participants were informed of the objectives and voluntariness of the research, through an informed consent, according to the Declaration of Helsinki (2013). These documents were reviewed and signed by each of the participants. Together with the above, permission was requested from the responsible entities of the club.

Procedures

Basic measurements

The height was evaluated by an ISAK II certified professional, with a mechanical Dry Wall Sizer 216, and the weight was recorded through the force platform, the subjects were instructed to place their hands on their hips and look straight ahead for 2 seconds, the data recorded during this time was averaged to obtain the body weight (newton) and divided by gravity ($-9.806 n/s^2$) (Chiu &Dæhlin, 2020) to obtain the body mass (kg.) (McMahon et al, 2018).

Vertical Jump Evaluation

CMJ was evaluated following the guidelines of Bosco's protocol (Bosco et al., 1983). Two previously validated PASCO PS-2142 force platforms were used (Lake et al., 2018). Players were required to position themselves which has their hands on their hips throughout the jump. Before the evaluation, a warm up type was used, divided into 3 blocks; general block, which consisted in performing joint mobility exercises as well as dynamic type stretching and ballistic type stretching which emphasized on the lower extremities.Followed a specific block where exercises on a coordination rail were used, performing 2 series of 3 repetitions, multi-jump on 15 cm fences 2 series of 3 repetitions and the final block where the CMJ jump was perform in quantity of 2 series of 2 repetitions. The whole warm up lasted approximately 10 minutes. The week before the evaluations, a session was held to familiarize the jumping technique.

Data collection and analysis

The data was processed through Pasco Capstone Software (version 1.13.4, USA), then exported to an Excel spreadsheet (version 16, Microsoft, USA), and finally the data was processed in Matlab, (version 9.6, USA). To estimate the start of the jump, the deviation of the subject's body weight was calculated, and when the force-time curve (f-t) dropped 5 standard deviations (SD) from the average subject weight (2000ms window in a still position) (McMahon et al., 2018). The beginning of the eccentric braking phase was calculated from the moment the curve returns to the value of the subject's weight and the end of this is when the subject's velocity returns to 0m/s. Velocity was derived from the f-t curve (McMahon et al., 2018). To calculate the FT, the time(s) from takeoff to the landing point was taken. The takeoff started when the force after the peak was less than 10N, and the second (landing) when it was greater than 10N (Lake et al., 2018). Finally, the JH was calculated indirectly, through the FT (G. L. Moir, 2008) (Figure 1). The RFD can be analyzed by time intervals, so it was calculated from the beginning of the eccentric phase to 50 and 100milliseconds later(Tillin et al., 2010).

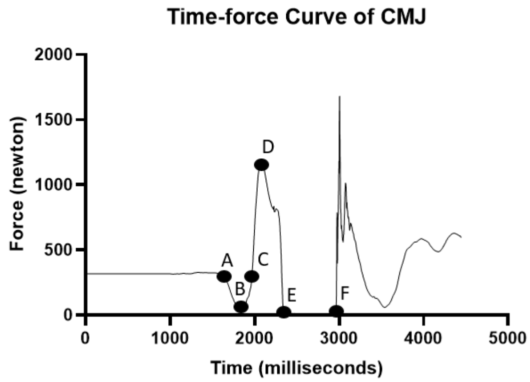

Figure 1. Point A, start of jump and unloading phase, when the curve exceeds -5SD of the subject's weight; point B, end of unloading phase and start of eccentric yielding phase, when the curve returns to the subject's weight; point C, end of eccentric yielding phase and start of eccentric braking phase; point D, end of eccentric braking phase and beginning of concentric phase, when the speed of the subject is 0m/s; point E, end of concentric phase and start of take-off, when the curve is less than 10n; point F, landing, when the curve is greater than 10n; point C to D, eccentric braking phase; point E to F, flight time.

Statistical Analysis

The descriptive statistics of the data were made, use statistics of mean (M) and standard deviation in all variables. The normality of the data was studied through the Shapiro-Wilk normality test, while Pearson's correlation test (r) was used to measure the relationships. The force of correlation was established from 0 to 0.1 trivial; 0.11 to 0.30 low; 0.31 to 0.49 moderate; 0.50 to 0.69 large; 0.70 to 0.89 very large; and 0.90 to 1.0 almost perfect to perfect, applying the same ranges for negative values (Hopkins, 2002). To know the level of prediction, linear regression tests were performed (r^2), where JH, JHn and FT were the dependent variables and RFD variables were the independent. All the statistics were carried out through the IBM SPSS statistics version 24.0® program. The significance was set as p>0.05.

Results

Table 1 shows the descriptive values of the variables derived from the f-t curve extracted from CMJ, presented as mean (M) and standard deviation (SD).

Table 1. Descriptive statistics of variables

	RFDe	RFDn	RFD_{0-50}	$RFDn_{0-50}$	RFD_{50-100}	$RFDn_{50-100}$	FT	JH	JHn
M	8073.81	152.23	9478.10	123.20	7710.20	100.48	0.55	37.55	21.18
±SD	2886.93	159.53	4377.09	55.82	2613.17	32.12	0.03	3.93	2.16

M mean; ±SD standard deviation; RFDe rate of force development of eccentric braking ;RFDr rate of force development normalized body weight ; RFD_{0-50}intervaled0-50ms; $RFDn_{0-50ms}$intervaled 0-50ms normalized to body weight; RFD_{50-100} rate of force development intervaled 50-100ms; $RFDn_{50-100}$ intervaled 50-100 msnormalized to body weight; FT flight time; JHjump height; JHn jump height normalized to subject height

No significant relationships were found between RFD variables with FT, JH and JHn. On the other hand, all the associations between the mentioned variables were low to moderate. Finally, the predictions (r^2) explained a %0.02 to 10.2% variance of the independent variables over the dependent ones (FT, JH and JHn).

Table 2. Relationships between variables of the force-time curve

		FT	JH	JHn
RFDe	r	0.307	0.319	0.234
	r^2	0.094	0.102	0.055
	p	0.176	0.158	0.306
RFDn	r	0.137	0.159	0.095
	r^2	0.019	0.025	0.009
	p	0.554	0.490	0.682
RFD_{0-50}	r	0.250	0.265	0.169
	r^2	0.063	0.070	0.029
	p	0.274	0.245	0.463
$RFDn_{0-50}$	r	0.249	0.267	0.230
	r^2	0.062	0.072	0.053
	p	0.275	0.241	0.316
RFD_{50-100}	r	0.100	0.088	-0.036
	r^2	0.010	0.008	0.001
	p	0.665	0.705	0.877
$RFDn_{50-100}$	r	0.100	0.090	0.063
	r^2	0.010	0.008	0.004
	p	0.667	0.697	0.785

p value, r of Pearson, r^2 linear regression, RFDe rate of force development of eccentric braking; RFDr rate of force development normalized body weight; RFD_{0-50} intervaled 0-50ms; $RFDr_{0-50}$intervaled 0-50ms normalized to body weight; RFD_{50-100} rate of force development intervaled 50-100ms; $RFDn_{50-100}$ intervaled 50-100 ms normalized to body weight; FT flight time; JH jump height; JHn jump height normalized to subject height.

Discussion

One of the main findings of this study was that no statistically significant associations were found between JH and FT, with the eccentric RFD variables. This agrees with some authors, who have not recommended the JH calculated through the FT, due to systematic measurement errors and low reliability, encouraged professionals to avoid this method (Chiu &Dæhlin, 2020), especially in elite athletes, or using other mathematical methods that take into account anthropometric characteristics of the subject (Morin et al., 2019) and it has also been recommended to expressly measure the rate of development of strength as a variable more sensitive to acute or chronic changes (Van Hooren&Zolotarjova, 2017). Similarly our results coincide with the findings of Barker et al., (2018), where they found no significant associations between total eccentric RFD (yielding more braking) and JH (r=0.097), it is worth noting that they calculated the JH through takeoff velocity ((take-off velocity)^2/(2*9.81)), finding significant associations with jump time (r=-0.826), recommending to include in the analysis the jump time and the reactive strength index modified (r=0.755),since it only found significant correlations between JH and concentric phase variables (Peak power, work and displacement) in CMJ, in fact it has been mentioned that the amounts that are mathematically related to those derived from time (rates of change) would allow a better measurement and evaluation of those transitory properties such as RFD (Lin et al, 2019).In contrast Mclellan et al., (2011) and Laffaye& Wagner (2013), found significant associations between JH and RFD, but in both studies they performed the jump with arm free movement as well as using other more reliable methods than FT to obtain the JH (momentum method). However, we did not find significant moderate associations between JHn and eccentric RFD, in this line, Rojas-Reyes et al., (2020) analyze the relationship of JHnand normalizedJH to lower limb length, finding that the latter is better associated and predicts absolute and normalized power to body weight.

It is recognized that there are limitations within the study, one of them being the method used to calculate the height of jump by means of the FT, since others, are more valid and reliable (Chiu &Dæhlin, 2020; KrÖll et al., 2017; Morin et al., 2019). It is also possible to use the kinematic method through 2D video analysis by calculating the JH based on the FT (Balsalobre-Fernandez et al., 2015). However, this method is valid if the center of mass travels upwards in the same way as when it descends, which would only happen if the sportsman takes off and lands in the same body position (Aragon, 2000). It would also be necessary to classify the sample according to playing positions, due to performance differences within the playing field (Buchheit et al., 2018) and could be reflected in RFD variables. In the review study by Slimani &Nikolaidis (2019), it has been shown that lower limb muscle power is affected by playing position, allowing for an understanding that different playing positions and tactical arrangements have specific physical demands (Soarez et al., 2012).

On the other hand, it is suggested for future studies, to use the kinematic method based on the analysis of the displacement of the center of mass during the vertical jump (Pelvic kinematic method) determining the height of the jump from the maximum height of the center of mass of the pelvis, minus the height of the foot, since it has demonstrated a concurrent validity (Chiu & Salem, 2010). Similarly, the "trochanter tracking" (TT) method is valid for determining jumping height with and without load. This approach (TT) by considering only the upward phase of the jump, takes hold, because it does not consider what happens after the highest point of the jump is reached (Chiu & Salem, 2010). Under this premise, Samozino et al. (2008) propose to incorporate the push off distance (h_{PO}), which determines the distance in which the force is exerted against the ground, obtaining a direct relation with the jump (Johnson &Bahamonde, 1996). Therefore, the formula to calculate the power of Samozino et al., (2008) which incorporates h_{PO}added to JH, is recommended to avoid the bias of evaluations that use FT to determine the power of the lower limbs (Aedo-Muñoz et al., 2020; Morin et al., 2019). Finally, we recommend to researchers relate the normalizedJH to the lower limb length to the RFD.

Conclusion

From the results found in this study, it is possible to conclude that the CMJ jump height calculated through the flight time and normalized to the height of the subject, does not present a significant association with the rate of development of eccentric braking force and normalized to body weight, which allows recognizing that the jump height is not a direct indicator of explosive force of the lower train, It is necessary, in order to know this performance indicator, to use direct methods such as force plates or other formulas that present a higher degree of validity and reliability, as well as other variables derived from the CMJ that present associations with the force development rate and thus avoid the bias of evaluations that use the flight time as an indicator of explosive force of the lower limb. However, further research is needed on methods to determine this indicator, also incorporating other variables that may be more sensitive to changes in neuromuscular status, in order to obtain a reliable assessment of athletes' performance.

Conflicts of interest

None of the authors present a conflict of interest.

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