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Relationship between strength parameters and squat jump performance in trained athletes

Relações entre diferentes parâmetros de força e a performance do *squat jump* em atletas treinados

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ABSTRACT

Squat jump (SJ) has been extensively used in training, yet analysis in trained athletes is scarce. Therefore, main research question was: what strength parameters can better explain the best SJ performance in trained athletes? Thirty five athletes performed 3 maximal SJ (using a 17kg bar) weighted jumps while ground reaction forces were sampled using a force platform synchronized with a linear transducer. Only the best attempt was taken for analysis. For the purpose of this paper the SJ was divided into the following two segments: the concentric segment 1 was defined from the initiation of movement until maximum positive velocity occurred; and the Concentric segment 2 was defined from the moment following the end of the Concentric segment 1 until take off velocity was achieved. No relationship was observed between SJ performance and impulse for concentric segment 1. However, a moderate but significant correlation (r = .63) was found between SJ height and impulse for Concentric segment 2. Additionally, a moderate significant association (r = .56) was observed between the SJ and the maximum rate of force development produced during the Concentric segment 1. The SJ showed important relations with peak and average power only for Concentric segment 1 (r = .57). As predictors, it's important that the force, power, and rate of force development must be maintained with high values of correlation to the height of the SJ but only during the concentric segment 1.
Keywords: power, force, impulse, rate of force development

RESUMO

O squat jump (SJ) tem sido extensivamente usado para controlar o treino, contudo, estudos realizados em atletas treinados são escassos. Assim, a principal questão de estudo foi: quais os parâmetros de força que melhor podem explicar a performance do SJ em atletas treinados? Trinta e cinco atletas realizaram 3 SJ com uma barra de 17 kg. A força exercida contra o solo foi medida com uma plataforma sincronizada com um medidor linear de posição. Somente o melhor salto foi analisado. A análise do SJ foi dividida em duas fases: concêntrica 1 que foi definida desde o início do movimento até se alcançar a máxima velocidade positiva; e a concêntrica 2 definida o momento em que acaba a fase concêntrica 1 até se atingir a velocidade de saída. Não foi observada nenhuma relação entre a performance do SJ e o impulso durante a fase concêntrica 1. Todavia, observou-se uma correlação moderada mas significativa (r = .63) entre a altura do SJ e o impulso da fase concêntrica 2. Para além disso, uma associação moderada significativa (r = .56) foi igualmente observada entre o SJ e a força explosiva produzida durante a fase concêntrica 1. O SJ revelou ainda relações significativas com o pico de potência e potência média, mas somente durante a fase concêntrica 1 (r = .57). Em suma, é importante que os valores de força, de potência e de força explosiva sejam mantidos durante a fase inicial do salto, isto é, durante a fase concêntrica 1, promovendo uma maior impulsão vertical.
Palavras-chave: potência, força, impulso, força explosiva

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The squat vertical jump (SJ) is a technique widely used to develop concentric-only leg extensor power, particularly in plyometric and power training programs (Aagaard, Simosen, Anderson, Magnusson, & Dyhre-Poulsen, 2002; Abernethy, Wilson, & Logan, 1995; Carlock et al., 2004; González-Badillo & Marques, 2010; Zatsiorsky, 1995). It is believed that by preceding the concentric jump action by a brief isometric hold lasting about two seconds, the athlete is unable to use the contribution from a stretch-shortening cycle. Despite this frequency of use, debate remains open as to what are the structural, neural, and mechanical variables that most influence the attainment of SJ height (González-Badillo & Marques, 2010).

Aragón-Vargas and Gross (1997a) found differences in vertical jump performance among individuals and change in performance with training have been object of many experimental studies, however, little information is available about kinematics factors that can better explain vertical jump performance in a large sample of trained athletes (González-Badillo & Marques, 2010). To the best of our knowledge, we have found only two studies prior to ours that examined the kinematics parameters linked to vertical jump height in a large sample of trained athletes (Dowling & Vamos, 1993; González-Badillo & Marques, 2010). Dowling and Vamos (1993) studied fifteen kinetic and temporal parameters in 97 trained/untrained men/women and observed that positive peak power was a strong predictor of vertical jump performance. More recently, González-Badillo and Marques (2010) reported strong correlations between vertical jump performance and the peak power produced during concentric phase (r = .812 − .851) and with the average power generated in the same phase (r =.829 − .870). The authors argued that is important that the force produced during the concentric phase must be maintained with high values of correlation to the height of the jump. In the same way, this study (González-Badillo & Marques, 2010) confirmed previous findings in which peak power was shown to be the best predictor of vertical jump height. Aragon-Vargas and Gross (1997b) examined within-subject differences in kinematics factors related to vertical jump performance in only eight participants and found that the take-off velocity was a significant predictor and accounted for approximately sixty percent of explained variation in jump height. Differences in vertical jump technique and/or coordination may exist between athletes and non-athletes; therefore it would be unique to evaluate kinematic parameters during vertical jump in highly trained individuals. Moreover, most of the previous studies used countermovement jump movement (CMJ) as preferred test and not squat jump. The biomechanical characteristics of these two vertical jumps allowed the possibility of studying contractile characteristics of individuals and the effect of prestretch (Bobbert, Gerritsen, Litjens, & Van Soest, 1996). However, few studies were not able to identify variables that accurately predict vertical jump (González-Badillo & Marques, 2010).

Like other physical abilities, SJ appears to be based upon a collection of several specific independent variables, each of which contributes to the overall effort. If these contributory variables were identified, subsequent investigations could be conducted to as certain how best to manipulate each independent variable in order to maximize its effect on jumping. Thus, the aim of this investigation was to examine the contribution of force, power, and impulse with SJ height in a group of trained male athletes. Confirmation of this would support the routine practice of applying such tests in early evaluation of training methods.

METHODS

Subjects

A group of 35 trained male track and field athletes (average age: 23.2, range 19-29 years) participated in the study. Before commencing the study all participants underwent physical examination and were cleared of any medical disorders that might limit full participation in the investigation. The study protocol was approved by the Research Ethics Committee and all volunteers provided informed consent following a verbal explanation of the study procedures and risks associated with participation.

Experimental Design

The present study used a cross-sectional experimental design to examine the relationship between kinematic factors during a jump and SJ height in a group of trained male athletes. Each athlete had experience with resistance training (around four years). Apart from normal technical and practice sessions (3 hours per day timed for 4:00 PM) and weekend competitions, all volunteers were involved in a 12 week resistance training program. Consequently, all the athletes were highly trained and familiar with the testing exercise.

Testing Procedures

Participants were familiar with the testing procedures since they had been performing the exercises as part of their normal training routine.

Following standardized warm-up participants performed three maximal SJ trials in a Smith machine while standing on a portable force platform (Isonet, JLML, Madrid, Spain). The bar of the Smith machine had a linear transducer attached (Isocontrol, JLML, Madrid, Spain) which was synchronized with the force platform. The force platform was connected to a portable computer and recorded data at a sample rate of 1000Hz. The rotary encoder of the linear transducer recorded the position and direction of the bar to within an accuracy of .0002 m. Peak power was calculated by the product of velocity taken with the linear transducer and the ground reaction force measured by the portable force platform.

Participants stood in the Smith machine and rested the bar (17 kg) on their shoulders. For the performance of the SJ test, subjects were asked to stand on the center of the force platform in a semi-squatting position. All athletes performed three SJ attempts without any countermovement after keeping the semi-squatting position for 3-4 seconds to avoid taking advantage of elastic energy storage. The SJ trials were performed with a knee angle of 90°, which was determined using a handheld goniometer (Q-TEC Electronic Co. Ltd., Gyeonggi-do, Korea). Athletes immediately jumped vertically by extending through hips. Hands remained holding on to the bar for the entire movement in order to maintain contact between the bar and shoulders. Three minutes of rest were provided between each trial to minimize the likelihood of fatigue. For the propose of this paper the SJ was divided into the following two segments: the Concentric segment 1 was defined from the initiation of movement until maximum positive velocity occurred, and the Concentric segment 2 was defined from the moment following the end of the Concentric segment 1 until take off velocity was achieved. Only the best attempt was taken to analysis.

Statistical Analyses

Standard statistical methods were used for the calculation of means and standard deviations. Intraclass correlation coefficient (ICC) was used to determine between-subject reliability of jumping tests (Table 1). Within-subject variation for all tests was determined by calculating the coefficient of variation (CV) as outlined by Hopkins (2000). Correlations were determined using Pearson's r. Statistical significance was accepted at $p \leq .05$ for all analysis.

RESULTS

The present study demonstrated high intraclass correlations (ICC) values (Table 1) for all parameters (.88 – .97). Moreover, the coefficient of variation (CV) was classified as moderate to high (6.8 – 17.0%). The best reliable parameter was reported for concentric 1 peak power (ICC: .97 and CV: 6.8%).

Table 1
Intraclass correlation coefficients (ICC) and coefficient of variation (CV) for linear transducer and force platform

	ICC (Range)	CV (%)
Linear transducer parameters		
Concentric 1 Peak Force (N)	.88 (.79 – .94)	17.0
Force platform parameters		
Concentric 1 Peak Force (N)	.93 (.87 – .96)	15.7
Concentric 1 Peak Power (W)	.97 (.93 – .98)	6.8
Concentric 1 positive velocity (m/s)	.89 (.80 – .96)	10.0

The present study found important relationships between SJ height and several metrics of strength (Table 2). No relationship was observed between SJ performance and impulse for Concentric segment 1. However, a moderate association ($r = .632$, $p < .001$) was found between SJ height and impulse for Concentric segment 2. Additionally, a poor correlation was reported between jump height and the peak force during the Concentric segment 1. A moderate but significant relation ($r = .561$, $p < .001$) was reported between the SJ and the maximum rate of force development produced during the Concentric segment 1. The SJ showed important relations with peak and average power only with the Concentric segment 1, respectively.

Table 2
Correlations (r) between SJ height and selected kinematic variables

	Best SJ	
	r	*p*
Concentric 1 Impulse (N.s)	*ns*	—
Concentric 2 Impulse (N·s)	.632	.000
Concentric 1 Peak Force (N)	.382	.028
Concentric 2 Peak Force (N)	*ns*	—
Concentric 1 RFD_{max} ($N \times s^{-1}$)	.561	.000
Concentric 1 Peak power (W)	.457	.007
Concentric 2 Peak power (W)	*ns*	—
Concentric 1 Average power (W)	.417	.016
Concentric 2 Average power (W)	*ns*	—

Note: ns = Non significant

DISCUSSION

The aim of the present study was to examine the factors causally associated to the squat jumping performance of trained male athletes. To our best knowledge, no study prior to ours examined with so much depth the variables that can explain the SJ performance in trained athletes as the one that present here. This study has had the worry to measure with instrumental severity and with highly reliability in the different variables. Moreover, the number of subjects has been considerable ($n = 35$), and in trained sportsmen population. The present data contributes important knowledge concerning determinant factors of SJ performance that have not been analyzed in a large data of trained athletes.

The impulse measured correlated significantly with SJ height for Concentric segment 2 ($r = .632$, $p < .001$). Ferragut, Cortadellas, Arteaga and Calbet (2003) also observed that the positive impulse explains 77% of countermovement jump height variation. This indicates that the product of the force generated and its duration of application have greater predictive values for vertical jump ability. In our case, the impulse produced following the end of the Concentric segment 1 until take off velocity was achieved explained almost 40% of SJ height. González-Badillo and Marques (2010) failed to observed significant relations between eccentric segment and countermovement jump height (from $r = .28$, $p > .05$ to $r = .40$, $p < .05$). These results are similar to those already published by Aragón-

Vargas and Gross (1997a), who also found a weak positive relationship between the vertical jump and the negative impulse ($.35 < r < .70$). Furthermore, Slievert and Taingahue (2004) investigated the relationship between sprint start performance (5 m time) and strength and power variables. The results indicated that negative impulse was negligible and showed no relationship with 5 m sprint time; however, propulsive impulse was substantial and significantly related to 5 m time ($r = -.64$, $p < .001$). Marques, Silva-Dias, Marinho and González-Badillo (2009) observed significant correlations ($r = -.60$ and $r = -.78$, $p < .05$) between SJ performance and short sprints, but not for propulsive impulse and peak power ($p > .05$). These results suggest that impulse it's only a good predictor during concentric phases.

In the present study, concentric peak force was significantly related with SJ performance for each trial ($r =.382$, $p = .028$) but only for Concentric segment 1. Cordova and Armstrong (1996) did not find any relation between the peak force and the jump performance with a single leg. According to the authors, the reduced number of participants evaluated ($n = 19$) could be an explanation for this lack of relation. In addition, although they found a high ICC (.94), the CV was excessively high, which is a negative indicator for the reliability of the metrics and might also influence the results. This problem is also apparent in the present study, since the reliability of the results was very similar (ICC: .93, CV: 19%). Other factors such as balance and protocol familiarization could have influenced the discrepant data.

The power output is one of the key predictors of performance in distinct athletic movements (Abernethy et al., 1995; Aragón-Vargas & Gross, 1997a, 1997b; Kawamori & Haff, 2004). Here, vertical jump height has been shown to have moderate correlated with the average and peak power during the concentric phase. The present study is not in agreement with others previously published. For example, Ashley and Weiss (1994) reported that peak power ($r = .80$, $p < .05$ to $r = .83$, $p < .01$) was the variable most associated with vertical jump. The present results were not a strong predictor and accounted for approximately seventeen percent of explained variation in jump height ($r = .46$). The peak power during jumping performance is always attained when the velocity is close to maximum value during the concentric phase and this maximum velocity is intimately linked to the takeoff velocity, which determines the jump height. Aragón-Vargas and Gross (1997a, 1997b) also claimed an important relation to the average power output.

These studies suggest that the power produced in the vertical jump is a factor strongly predictive of height attainment in the countermovement vertical jump. Nevertheless, these findings were not supported by our study. Although the present experiment found that the average power was related with the SJ height, this parameter could only explain about 16 percent of the best attempt ($r = .42$, $p < .05$).

The present data contribute important knowledge concerning determinant factors in vertical jump performance that to date have not been analyzed in large data samples of trained athletes. As predictors, it's important that the force, power, and rate of force development must be maintained with high values of correlation to the height of the SJ from the initiation of movement until maximum positive velocity occurred.

Practical Applications

Improvement in jumping ability is a major training goal for many sports, and squat jumping is a well-recognized training exercise used to achieve this. In individual sports like track and field, athletes must improve jump performance in order to achieve better personal best records. These findings should be interpreted with caution since correlations do not signify causation, so additional research is required to clarify whether improvements in lower body strength, velocity or power as a result of resistance and/or plyometric training will indeed improve jumping ability in trained track and field athletes.

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