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RELATIONSHIP BETWEEN SPRINT ABILITY AND LOADED/UNLOADED JUMP TESTS IN ELITE SPRINTERS

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Running title: Relationship between jump tests and sprint performance

Abstract

The neuromechanical determinants of sprint running performance have been investigated in team sports athletes and non-elite sprinters. The aim of this study was to quantify the relationships between kinetic and performance parameters, obtained in loaded and unloaded vertical and horizontal jumps, and sprinting in elite athletes. Twenty-two sprinters performed squat jumps, countermovement jumps, horizontal jumps and jump squats with different loads on a force platform, in addition to a 50-m sprint. Results indicated that jumping height and distance in vertical and horizontal jumps are more strongly correlated ($R^2 \approx 0.81$) to sprinting speed than the respective peak forces ($R^2 \approx 0.36$). Furthermore, the optimum load generating the maximum power in the jump squat is also highly correlated to sprint performance ($R^2 \approx 0.72$). These results reveal that vertical and horizontal jump tests may be used by coaches for assessing and monitoring qualities related to sprinting performance in elite sprinters.

Key words: Olympic athletes; optimal load; propulsive power; velocity; strength; track & field.

Introduction

Sprinting is an important component of several track and field events (e.g., 100- and 200-m, long jump, etc.). Consequently, a great deal of effort has been expended in identifying the physical capabilities most strongly associated with maximum running speed. Propulsive forces in the horizontal plane during ground contact are positively correlated to sprinting performance both in the acceleration phase (15) and in the full 100-m distance (17). Accordingly, several studies have attempted to identify potential predictors of sprinting performance using simple and time-saving laboratory tests focusing on strength-power parameters obtained in vertical and horizontal jumping and weight lifting assessments (21, 22). This is based on the assumption that the kinetic variables obtained in these tests are highly correlated to the ability to produce force rapidly during sprinting, thus influencing step frequency, contact and swing time (17). In general, it is recommended that the individual values of force production are expressed relative to body mass to account for differences in anthropometric characteristics.

Average power, peak power, peak force, rate of force development and peak velocity obtained in the split-squat and traditional squat at a range of external loads ranging from 30-70% of one repetition maximum have shown to be moderately correlated (r = -0.40 to -0.68) with 5-m sprint time in team sports players (21). In track and field athletes, the height attained in the squat jump, countermovement jump and drop jump, in addition to the reactive strength index (i.e., the height of the jump divided by ground contact time, during a depth jump) explained 89.6% of mean velocities in several sprinting distances (22), although the sample size was relatively large (n = 25), and the sprinters were young and performed at regional level. In a study with a smaller sample size (n = 5), the countermovement jump peak force relative to body weight predicted maximal velocity over 10-m ($R^2 = 0.83$) (13).

It is clear from the literature that there are a lack of studies which include a representative sample of high-level sprinters performing strength-power tests in order to identify the best correlates of speed performance. This information could assist coaches in choosing appropriate tests to be used in the monitoring of training effects and identifying potential weaknesses in the strength-power characteristics which need to be corrected using different training strategies. Predicting high-level sprinting performance by means of simple tests may also facilitate national surveys to identify talent in track and field speed events, in both men and women.

Therefore, the aim of this study was to test the correlations between vertical and horizontal jumping tests and sprinting performance, along with the load which produces the highest power output in squat jumping with different weights on the bar, in top-level sprinters of both sexes. Moreover, we investigated whether strength/power performance differences would arise between the sexes in this particular group of elite athletes. Our hypotheses were twofold: 1) even in this group, strength/power sex-based differences would be significant and, 2) for elite sprinters, the mechanical outputs presented during jumps performed in loaded and unloaded conditions would be highly correlated to sprinting performance.

Methods

Experimental Approach to the Problem

A cross-sectional correlational design was used to investigate the existence of relationships between selected strength and power parameters, collected in vertical and horizontal jumping tests, and sprinting ability in elite sprinters. To analyze the correlations between jump and sprint performances in different conditions of applied force, we used the following variables: height, power, the distance of loaded and unloaded jumps and sprint performance over different distances (10-, 30- and 50-m). Moreover, a regression-based approach was used to identify effective models for determining sprinting speed in a representative sample of elite sprinters in order to assist coaches to focus on performance factors to be trained and assessed in the training process.

Subjects

Twenty-two elite sprinters who were top-ranked at the Brazilian Track & Field Confederation (13 men and 9 women; age: 23 ± 5 years; height: 1.71 ± 0.11 m and body mass: 67.22 ± 13.92 kg) volunteered to participate in the study. The sample comprised athletes who were Olympic, Pan-American and National medalists, thus attesting to their high level of competitiveness. The tests were carried out at the beginning of the pre-season, prior to the first phase of the competitive period. The athletes were submitted to the following training program during the assessment period: sprint specific training: three 45-60 minute sessions per week; power/strength/plyometric training: four 45-60 minute sessions per week; technical drills: five 30-45 minute sessions per week. Athletes were briefed on the experimental risks and benefits of the study, and signed a written informed consent agreeing to take part. The study was approved by the local Ethics Committee.

Testing standards

The athletes were familiar with the testing procedures prior to the study due to their routine of training and assessments which used the same exercises, tests, equipment and facilities. The tests were performed at the regular training time. All athletes received standard instructions on required behavior prior to commencing the tests, including a minimum of 8-h of sleep, balanced nutrition and avoiding beverages and food containing alcohol and caffeine. They were also required to report to the laboratory in a hydrated state.

Vertical jump assessment

Before performing the vertical jump tests, the athletes completed a 20-minute standardized warm-up, including 15 minutes of general (i.e., 10-min running at a moderate pace followed by 5-min of lower-limb active stretching) and 5 minutes of specific exercises (i.e., sub-maximum attempts at squat and countermovement jumps). Jumping height and peak force in the squat and countermovement jumps were determined using a force platform with custom designed software (AccuPower, AMTI, USA), which sampled at a rate of 400 Hz (23). In the squat jumps, the athletes were instructed to maintain a static position with a ~90° knee flexion angle for 2 seconds before the attempts, without any preparatory movement. For the countermovement jumps, the subjects started from an upright position, performing a rapid downward movement followed by a dynamic complete extension of the lower limb joints. To avoid undesirable changes in jump coordination, sprinters freely determined the amplitude of the countermovement. Squat and countermovement jumps were executed with both hands on the hips throughout the full range of the movements. Sprinters performed six attempts at each jump (i.e., squat and countermovement) with a 15-second rest interval between the jumps. The highest attempt from each type of jump was used for further analysis.

Horizontal jump assessment

Athletes were positioned on the force platform, performing the horizontal jump tests from a standing position. They were instructed to commence the jump by swinging their arms and bending their knees to provide the maximal forward drive. The take-off line was drawn on the force platform, positioned immediately adjacent to a jump sandbox. The jump length was determined using a metric tape measure (Lufkin, L716MAGCME, Appex Group, USA). The measurement was taken from the take-off line to the nearest point of contact on the landing (i.e., back of the heels). Peak force was assessed using a force platform, as described above. Each athlete was allowed three attempts and the longest distance reached was recorded for further analysis.

Sprint speed assessment

Sprinters performed a flying start 50-m test to assess maximum sprinting speed. Five pairs of photocells (Smart Speed, Fusion Equipment, Australia) were positioned at distances of 0-, 10-, 30- and 50-m. Athletes started each attempt 5-m behind the first photocell-timing gate, accelerating as much as possible before crossing the starting line. They performed two attempts, with a 5-minute rest interval between the trials. The best 50-m performance was used for correlational analyses.

Assessment of mean propulsive power, magnitude of the optimum load and velocity with a load corresponding to 40% of body mass in the jump squat

Mean propulsive power was assessed by means of the jump squat exercise executed on a Smith machine (Technogym Equipment, Italy). Athletes were instructed to perform 3 repetitions at maximal velocity for each load, starting at 40% of their BM.

Subjects executed a knee flexion until the thigh was parallel to the ground, then, following a command to start, jumped as quickly as possible without their shoulder losing contact with the bar. Loads of 10% of BM were progressively added in each set until a decrease in mean propulsive power was observed. A 5-minute rest interval was provided between sets. We used a linear transducer (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) attached to the Smith machine bar to obtain the mean propulsive power value. The finite differentiation technique was used to calculate bar velocity and acceleration. The bar position data were sampled at 1,000 Hz using a PC (Toshiba Satellite, Toshiba Computers, Japan). Mean rather than peak propulsive power was used as Sanchez-Medina et al. (20) observed that mean mechanical values during the propulsive phase better reflect the differences in neuromuscular potential between individuals. This approach avoids underestimation of the true strength potential as the higher the mean velocity (and lower the relative load), the greater the relative contribution of the braking phase to the entire concentric time. We considered the maximum mean propulsive power value and the absolute load used to obtain this variable (i.e., optimum load) for further analysis. We selected the highest velocity obtained in the jump squat attempts using a load corresponding to 40% of BM for correlation analysis.

Statistical Analysis

Data are presented as mean ± SD. The dependent variables in this study were the sprinting speeds at 10-, 30- and 50-m. The independent variables were the variables collected in the horizontal and vertical (loaded and unloaded) jump tests. A Pearson product-moment coefficient of correlation was used to analyze the relationships between these variables, being calculated for each sex separately and for both sexes together. As the association levels did not differ between sexes, men and women were grouped together and only the significant correlations for all sprinters were reported. The associations were expressed in shared variance (R^2) to test the hypothesis that jumping ability is strongly related to sprint performance. Data normality was checked via the Shapiro-Wilk test. Simple linear regression models were calculated using the vertical and horizontal jump height/distance to determine the best predictors of the velocity at 10-, 30- and 50-m for each sex, in order to help coaches estimate the extent of change in sprinting speed to a given change in jump performance. Total variance was reported by the coefficient of determination (R^2) and the respective level of significance (*p* value). In addition, parameter estimate (*B*), standard error (SE), standardized estimates (□ coefficients), and t values were also described. An independent Student t-test was used to compare men and women in all the assessed variables. Intraclass correlations (ICCs) were used to indicate the relationship within vertical (i.e., loaded and unloaded conditions) and horizontal jumps for height, distance, peak force and mean propulsive power. The ICC was 0.93 for the loaded squat jumps, 0.95 for the SJ and CMJ, and 0.94 for the horizontal jumps. The statistical significance level for all the analyses was set at $P < 0.05$.

Results

Kinetic and performance indices obtained in sprint and jump tests by men and women sprinters are presented in table 1. All the measures were higher in men than in women.

*****Insert table 1 here*****

Table 2 displays all the correlation coefficients among horizontal and vertical jump kinetic and performance indices and sprint velocities over 10-, 30- and 50-m. Correlations were very high ($R^2 \approx 0.81$) between vertical jump height and horizontal jump distance and sprint performance. These correlations were substantially greater than those documented between peak forces in vertical jumps and sprint performance ($R^2 \approx 0.13$). The correlation between peak force in horizontal jumps and sprinting approached an R^2 of 0.64. Correlation coefficients between mean propulsive power in the jump squats corresponding to 40% of body mass and sprint performance amounted to an $R^2 \approx 0.81$, which were slightly higher than the correlations between the optimum load generating the maximum power in jump squat and sprint performance ($R^2 \approx 0.72$).

*****Insert table 2 here*****

For practical and applied purposes, the results of simple regression analyses between velocity at 10-, 30-, and 50-m and vertical and horizontal jump height/distance in elite men and women sprinters are presented in table 3, separated by the sex.

*****Insert table 3 here*****

Discussion

The results of this study indicate that the horizontal, vertical and loaded vertical jump performance is strongly correlated with sprinting speed in elite sprinters. In this study, the distances jumped in horizontal and vertical jumps were almost perfectly associated (4) with the maximum speed presented at 10-, 30- and 50-m in the sprint tests. Moreover, the magnitude of the load lifted by sprinters at the optimum power zone (for the jump squat exercise) (10) was also strongly correlated with the sprint performance in this group of athletes. This is the first investigation to find these relationships in top-ranking sprinters, and the results confirmed our hypothesis that the mechanical principles related to the ability of applying force in vertical/horizontal jumps would be connected to sprinting faster.

Hudgins et al. (5) have already reported strong correlations between horizontal jump and sprint performance at 60-, 100-, and 200-m (*r* = 0.97, 1.00, and 0.97, respectively). Despite the differences between our test protocol (single horizontal jump test) and the protocol followed in the above mentioned investigation (multiple horizontal jump tests), the associations between horizontally jumped distance and speed ability described by these authors were very similar to the ones documented herein (R^2 = 0.90, 0.88, and 0.86, for 10-, 30-, and 50-m, respectively). Although our data showed important correlations between the distance jumped and sprinting speed, the peak force produced during horizontal jumps presented weaker values of correlation ($R^2 \approx 0.64$, for all assessed distances). It is possible that the sprinters' ability to transfer the linear momentum of force directly from the floor to push their bodies forward may be more important to reach higher speeds than the total ground reaction forces produced during horizontal jumps.

The results obtained in the present study are in accordance with a number of previous investigations demonstrating significant relationships between vertical jumping ability and sprint performance (1, 6-8). We found two investigations examining these correlations in elite and sub-elite sprinters. In the first study, Kale et al. (6) stated that squat and countermovement jumps were significantly correlated with performance in a 100-m sprint test (*r* = 0.46). Similarly, Faccioni (3) described significant correlations between countermovement jumps and the maximum speed reached by elite and sub-elite sprinters during specific speed testing (r = 0.72). It should be mentioned that the association values between vertical jump performance (squat and countermovement jumps) and sprinting speed presented in this study are much higher than the values obtained in the aforementioned investigations ($R^2 \approx 0.81$, for 10-, 30-, and 50-m). It appears that the competitive level of the sprinters affects the relationship between vertical jump heights and sprint ability. The elite men and women sprinters in this study have faster performance times in the 100-m dash race than the athletes who participated in the above-mentioned studies and have, on average, their personal records (for time measurements, in seconds) ≈ 9 % longer than the 100-m world record (i.e., < 10.36 and < 11.40 seconds, men and women, respectively). Moreover, it is possible that improvements in vertical jump height in this particular group of athletes can result in improved sprint performances. This issue deserves future investigations with longitudinal designs.

Interestingly, also for vertical jumping assessments (squat and countermovement jumps), the relationships between jump peak force and 10-, 30-, 50-m sprint performance were weaker than the same correlations obtained using the jumped heights ($R^2 \approx 0.36$ against $R^2 \approx 0.81$, for sprint/peak force correlations, and for sprint/jumped height correlations, respectively). Nevertheless, it is worth noting that the maximum ground reaction forces produced by the sprinters during vertical jump attempts are directly dependent on the body mass magnitude (11, 12). On the other hand, the height jumped by each athlete is able to be expressed as a value already adjusted for individual body mass. It is conceivable that the body mass relative performance outcomes may be more associated with the maximum speed reached by a group of elite sprinters, who have to move their bodies forward as fast as possible over a short distance. Additionally, from a practical point of view, it allows coaches to control/evaluate their sprinters without using force platforms, which facilitates monitoring of sprinters' performance in a specific track & field environment.

In line with previous research (9, 14, 25), we found strong relationships between the variables collected in the loaded jump squat (mean propulsive power and velocity with 40% of BM) and sprint performance ($R^2 \approx 0.81$, for all assessed distances). These data may be partially clarified by analyzing the significant intercorrelations ($p < 0.05$) between the countermovement jumps and jump squats performed with a different range of loads (2, 9). In this regard, subjects capable of jumping higher using additional loads are probably able to perform better in unloaded jump tests. Additionally, ballistic exercises (e.g., loaded and unloaded jump squat exercises) are similar to the sprint-movement patterns, since they allow both projection and lifting of the subject, and have acceleration and deceleration phases (18, 19). It seems reasonable to assume that the mechanical characteristics of ballistic exercises may significantly increase the correlations between this mode of exercise and sprint ability and highlights the importance of mixing light and/or moderate loads and high-velocity movements in training.

This is the first study to show nearly perfect correlations (4) between the magnitude of the load lifted at the optimum power zone (10) and the maximum speed reached by elite sprinters at 10-, 30-, and 50-m ($R^2 \approx 0.81$). The fact that force production is critical in sprinting performance has already been established (16, 24). As described by Sanchez-Medina et al. (20), there is a relative load spectrum (based on a percentage of the one-repetition maximum) capable of maximizing the power output. This means that in theory the higher the one-repetition maximum value, the greater the magnitude of the optimum load. Consequently, it could be concluded that power production capacity is dependent on the athletes' maximum strength level. However, strong correlations do not necessarily imply cause and effect, therefore, we are not able to confirm whether an increase in the optimum load magnitude would result in an improved sprint performance. This issue deserves longitudinal studies aimed at enhancing optimum load and establishing its relationship with changes in sprint performance by means of specific training strategies (e.g., concurrent maximal strength and plyometric training).

In conclusion, the neuromuscular performance assessed using various horizontal and vertical loaded/unloaded jumps was highly correlated with the maximal velocity reached by elite sprinters at 10-, 30- and 50-m. Distance and height of horizontal and vertical jumps, respectively, are more strongly correlated with sprinting speed than peak force measured by the force platform. Mean propulsive power and velocity in the loaded jump squat with 40% of BM and the load lifted at the optimum power zone are also highly correlated with sprinting ability, suggesting that maximal strength and power development are important for athletes to achieve higher velocities over a 50-m distance.

Practical applications

We found strong correlations between loaded/unloaded vertical and horizontal jump tests and sprint performance in elite sprinters. From a practical point of view, due to the strong relationships documented herein, track & field coaches are encouraged to frequently assess sprinters' performance and training level through the use of simple, safe and time-saving jumping tests. This is especially indicated during the competitive phases, when coaches avoid testing "real speed" in athletes close to the peak performance moment due to the high risk of muscle injury involved in sprint events. In sports labs and with time available to evaluate strength-power capabilities, coaches are also encouraged to use jump squats with different loads, and determine the optimum power zone. This load may be used both to monitor sprinting performance and to prescribe training sessions for developing sprinter's specific lower body strength and power.

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Table 1. Sprinting and jumping performance of men (n = 13) and women (n = 9) sprinters. V 10m – velocity at 10-m; V 30m – velocity at 30-m; V 50m – velocity at 50-m; VJS40% - velocity in jump squat with load corresponding to 40% of body mass; MPPJS - mean propulsive power in jump squat; SJ – squat jump; CMJ – countermovement jump; HJ – horizontal jump distance; PF SJ – peak force during squat jump; PF CMJ – peak force during countermovement jump; PF HJ – peak force during horizontal jump; OL – optimal load associated with maximum power.

	Men	Women
V 10 m (m/s)	7.62 ± 0.16*	7.09 ± 0.14
V 30 m (m/s)	8.67 ± 0.23*	7.96 ± 0.21
V 50 m (m/s)	9.10 ± 0.29*	8.30 ± 0.21
VJS40% (m/s)	1.38 ± 0.07*	1.22 ± 0.08
MPPJS (W)	1098 ± 278*	562 ± 107
SJ (cm)	44.32 ± 6.30*	33.22 ± 3.52
CMJ (cm)	45.80 ± 5.41*	34.86 ± 4.31
HJ (m)	2.84 ± 0.18*	2.37 ± 0.10
PF SJ (N)	2551 ± 786*	1767 ± 255
PF CMJ (N)	2447 ± 652*	1607 ± 206
PF HJ (N)	1899 ± 433*	1177 ± 50
OL (kg)	83.53 ± 21.18*	44.62 ± 8.77

*Significant different to women (*P* < 0.05)

Table 2. Correlations between horizontal and vertical jump performance indices and sprint performance (n = 22). V 10m – velocity at 10-m; V 30m – velocity at 30-m; V 50m – velocity at 50-m; VJS40% - velocity in the jump squat with a load corresponding to 40% of body mass; MPPJS - mean propulsive power in the jump squat; SJ – squat jump; CMJ – countermovement jump; HJ – horizontal jump distance; PF SJ – peak force during the squat jump; PF CMJ – peak force during the countermovement jump; PF HJ – peak force during the horizontal jump; OL – optimum load associated with maximum power.

	V 10m (m/s)	V 30m (m/s)	V 50m (m/s)	VJS40% (m/s)	MPPJS (W)	SJ (cm)	CMJ (cm)	HJ (m)	PF SJ (N)	PF CMJ (N)	PF HJ (N)	OL (kg)
V 10m (m/s)	-	0.964**	0.944**	0.822**	0.777**	0.795**	0.857**	0.904**	0.261*	0.354**	0.591**	0.729**
V 30m (m/s)	0.964**	-	0.986**	0.839**	0.783**	0.767**	0.840**	0.881**	0.283*	0.332**	0.617**	0.727**
V 50m (m/s)	0.944**	0.986**	-	0.806**	0.781**	0.756**	0.820**	0.863**	0.272*	0.309**	0.638**	0.719**
VJS40% (m/s)	0.822**	0.839**	0.806**	-	0.762**	0.783**	0.811**	0.762**	0.308**	0.418**	0.540**	0.707**
MPPJS (W)	0.777**	0.783**	0.781**	0.762**	-	0.702**	0.719**	0.855**	0.498**	0.600**	0.913**	0.976**
SJ (cm)	0.795**	0.767**	0.756**	0.783**	0.702**	-	0.885**	0.777**	0.173	0.266*	0.469**	0.620**
CMJ (cm)	0.857**	0.840**	0.820**	0.811**	0.719**	0.885**	-	0.868**	0.248*	0.316**	0.506**	0.667**
HJ (m)	0.904**	0.881**	0.863**	0.762**	0.855**	0.777**	0.868**	-	0.327**	0.375**	0.729**	0.799**
PF SJ (N)	0.261*	0.283*	0.272*	0.308**	0.498**	0.173	0.248*	0.327**	-	0.808**	0.586**	0.599**
PF CMJ (N)	0.354**	0.332**	0.309**	0.418**	0.600**	0.266*	0.316**	0.375**	0.808**	-	0.608**	0.697**
PF HJ (N)	0.591**	0.617**	0.638**	0.540**	0.913**	0.469**	0.506**	0.729**	0.586**	0.608**	-	0.910**
OL (kg)	0.729**	0.727**	0.719**	0.707**	0.976**	0.620**	0.667**	0.799**	0.599**	0.697**	0.910**	-

*significant at *P* < 0.05

**significant at *P* < 0.01

Table 3. Results of simple regression analyses between velocity at 10-, 30-, and 50-m and vertical and horizontal jump height/distance in elite men and women sprinters.*

		MEN (n=13)						***WOMEN (n=9)***					
VARIABLE	***PREDICTOR***	*B*	*SE*	*Stand. est.*	*t*	*p*	*R²*	*B*	*SE*	*Stand. est.*	*t*	*p*	*R²*
	SJ	0.021	0.005	0.800	4.416	0.001	0.639	0.034	0.011	0.767	3.164	0.016	0.588
V 10m	***CMJ***	0.027	0.005	0.871	5.885	< 0.001	0.759	0.030	0.009	0.798	3.502	0.010	0.637
	HJ	0.753	0.152	0.830	4.940	< 0.001	0.689	1.419	0.275	0.890	5.167	0.001	0.792
	SJ	0.027	0.008	0.727	3.513	0.005	0.529	0.053	0.014	0.818	3.763	0.007	0.669
V 30m	***CMJ***	0.036	0.007	0.833	5.002	< 0.001	0.695	0.044	0.013	0.799	3.521	0.010	0.639
	HJ	1.054	0.208	0.836	5.059	< 0.001	0.699	1.758	0.595	0.745	2.953	0.021	0.555
	SJ	0.034	0.010	0.718	3.425	0.006	0.516	0.046	0.017	0.713	2.691	0.031	0.508
V 50m	***CMJ***	0.045	0.010	0.818	4.724	0.001	0.670	0.038	0.015	0.696	2.565	0.037	0.484
	HJ	1.302	0.297	0.797	4.382	0.001	0.636	1.594	0.638	0.687	2.500	0.041	0.472

* V 10m, V 30m and V 50 m = velocity at 10-, 30-, and 50-m, respectively; SJ = squat jump height; CMJ = countermovement jump height; HJ = horizontal jump distance; = parameter estimate; SE = standard error; Stand. est. = standardized estimate; R^2 = proportion of variance explained by the regression model.