FORCE-VELOCITY RELATIONSHIP BETWEEN SPRINTING AND JUMPING TESTING PROCEDURES

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The aim of this study was to examine the relationship between the mechanical characteristics of the horizontal and vertical Force-velocity (F-v) profile as well as the performance variables of the sprinting and jumping testing procedures. Twenty high-level sprinters performed two maximal sprints and squat jumps against multiple external loads. Our main findings revealed very large correlations for maximal mechanical power output (P_{max}) (r=0.72), as well as for performance variables between the sprinting and jumping tasks (r=-0.81) and large correlations for maximal velocity (V_0) (r=0.66). The maximal force (F_0) and the slope of the F-v relationship *(F-v slope)* were not significantly correlated between both tasks. These results suggest that both testing procedures should be performed in order to gain a deeper insight into the maximal mechanical properties and function of the lower-body muscles in high-level sprinters.

KEYWORDS: Force-velocity profile, Force-velocity relationship, sprinting performance

INTRODUCTION: Sprinting and jumping are fundamental qualities for several sports. Sprinting is a cyclic locomotion depended on the mechanical capabilities of the neuromuscular system. Jumping is a form of ballistic push-off movement, in which the mechanical function of the lower limbs' neuromuscular system depend on the lower limbs maximal power capabilities and the optimal force-velocity (F-v) profile of each athlete (Samozino et al., 2012; Jiménez-Reyes et al., 2016). Sprinting and jumping mainly represents the ability of athletes' neuromuscular system to produce high level of force, effective transmit the generated force onto the supporting ground and maintain this force at high contraction velocities (Morin and Samozino, 2016).

A biomechanical model, based on kinematics and kinetics parameters of the runner's body center of mass (CM) during sprint-acceleration and loaded squat jumps (SJ), allow to determinate the F-v, and power-velocity (P-v) relationships (Samozino et al., 2008, 2016). The horizontal (sprinting task) and vertical (jumping task) F-v profiles are described by the theoretical maximal values of: force (F_0), velocity (V_0), and power (P_{max}), as well as by the slopes of the linear F-v relationship (*F-v slope*) (Morin and Samozino, 2016). Due to the differences in the force vector between sprinting acceleration (horizontal) and jumping (vertical) procedures, it would be interesting to examine the relationship between the same mechanical characteristics obtained from both tasks. The aim of this study was to examine the relationship between the same variables (F_0, V_0, P_{max}, *F-v slope*) of the horizontal and vertical mechanical F-v profile as well as the performance variables (time to 15-m and maximal squat jump height, respectively). We hypothesized that the relationship between the mechanical characteristics of both tasks could be weak.

METHODS: Twenty high-level sprinters (13 females and 7 males, Mean ± SD: age 23.4 ± 4.7 years; body mass 64 ± 9.1 kg; height 1.72 ± 0.09 m; males 100-m personal best (pb) ranging from 10.22 to 10.99 s and females 100-m pb ranging from 11.44 to 12.68 s) gave their written informed consent to participate in this study, which was approved by the local ethical committee, in agreement with the Declaration of Helsinki.

Participants were involved in two different testing sessions, within the same week, in an indoor stadium. Prior to each session, participants performed a standardized sprint warm-up, which included dynamic stretching. At the first testing session, each athlete performed two maximal sprints of 30-m from a three-point crouching position with 5 min of rest between trials. Six different split times were determined at 5, 10, 15, 20, 25 and 30-m. The time data of each sprint was recorded by a high-speed camera (Casio EX-F1, Tokyo, Japan) sampling at 300 Hz, which was placed on a tripod, 10-m away from the runway at the half of sprinting distance (15-m). The video parallax error was corrected to ensure the different split times were measured properly (Romero-Franco et al., 2017). At the second testing session participants performed six to seven vertical maximal Squat Jumps (SJ). The first jump was performed without load whereas the rest of the jumps were performed with progressively increasing extra loads ranging from 20% to 100% of body mass. Two valid trials were performed with each load with 3 min of recovery between trials. The starting position was self-selected by the participants before the trial and was kept fixed for the subsequent trials using a marker on the squat cage to maintain the same squat depth throughout the test (Giroux et al., 2015). The participants were asked to maintain their starting position for about 1 s and then apply force as fast as possible and jump for maximum height. The push-off distance (h_{po}) was calculated as the difference between lower limb length (distance from great trochanter to tip of the toes with extended lower limps) and starting height at the squat jump (vertical distance from greater trochanter to ground). Jump heights were obtained by using an optical measurement system (OptoJump Next Microgate, Italy). The best trial of each load being considered for analysis in order to determine the components of the horizontal and vertical F-v profile according to Samozino's methods (Samozino et al., 2008, 2016).

The entire F-v relationship represents the maximal theoretical horizontal force (normalized to body mass) that the lower limbs could produce over one contact at a null velocity (F_0) and the theoretical maximum velocity that could be produced during a support phase in the absence of mechanical constraints (V_0). These variables were calculated as extrapolated from the linear sprint F–v relationship. Multiplying horizontal F and v values for each support phase, the equivalent of maximal mechanical power output (P_{max}, normalized to body mass) in the antero-posterior direction is obtained and computed as $P_{max} = F_0 \times V_0 / 4$ (Samozino et al., 2016). Finally, 15-m time was determined from the modelled velocity–time data. For the vertical F-v profile, the intercepts of the F-v relationship represents the maximal external force lower limbs could produce during a theoretical extension movement at null velocity (F_0) as well as the maximal velocity at which lower limbs could extend during a theoretical extension under zero load (V_0). The apex of the P-v relationships is the maximal power output lower limbs can produce over one extension and computed as $P_{max} = F_0 \times V_0 / 4$. The slope of the linear F–v relationship corresponds with the balance between force and velocity capabilities and computed as $F\text{-}v\ slope = – F_0 / V_0$ (Samozino et al., 2008). The high reliability and validity of the Samozino's method to determine the F-v profile from the sprinting and jumping testing procedures has been reported elsewhere (Giroux et al., 2015; Samozino et al., 2008, 2016). Data were analyzed with statistical software (IBM SPSS version 25.0, Chicago, IL, USA) Before analyses, all variables were checked for normality, using the Shapiro-Wilks test. Pearson's correlation coefficients (r) were used to test the relationship between the variables of the mechanical F-v profile (F_0, V_0, P_{max}, *F-v slope*) and performance (time to 15-m and maximal SJ height). A *P* value of 0.05 was accepted as level of significance.

RESULTS: The descriptive data and the correlation coefficients between the same mechanical properties of the horizontal and vertical F-v profile as well as of the performance variables are shown in Table 1.

Table 1. Descriptive data (Means ± Standard Deviation) and correlations coefficients between the mechanical F-v profile and performance variables displayed by sprinting (horizontal) and jumping (vertical) tasks.

Variable	Mean (SD)	*r*	r^2	*P*
F_0 *($N·kg^{-1}$)*				
Horizontal	8.37 ± 0.9	0.15	0.02	*> 0.05*
Vertical	39.2 ± 5.7			
V_0 *($m·s^{-1}$)*				
Horizontal	9.31 ± 0.8	**0.66***	0.44	*= 0.001*
Vertical	2.99 ± 0.6			
P_{max} *($W·kg^{-1}$)*				
Horizontal	19.56 ± 3.4	**0.72****	0.52	*< 0.001*
Vertical	28.97 ± 6.4			
F-v slope *($N·s·m^{-1}·kg^{-1}$)*				
Horizontal	0.9 ± 0.09	0.17	0.03	*> 0.05*
Vertical	-13.8 ± 3.9			
Performance				
Time to 15-m *(s)*	2.66 ± 0.1	**-0.81****	0.66	*< 0.001*
Squat Jump *(cm)*	38.4 ± 7.1			

Significant correlations (highlighted in bold): *$*P < 0.05$, $**P < 0.001$*. Qualitative interpretations of the Pearson's correlations coefficients: small *(r=0.1–0.3),* moderate *(r=0.3–0.5),* large *(r=0.5–0.7),* very large *(r=0.7–0.9)* and nearly perfect *(r>0.9)* (Hopkins et al., 2009).

DISCUSION: The aim of this study was to examine the relationship between the same mechanical characteristics of the horizontal and vertical F-v profiles as well as the performance variables between both testing procedures. Our main findings revealed very large correlations for P_{max}, as well as for performance variables and large correlations for maximal velocity V_0 between the sprinting and jumping procedures, respectively. The relationship between the variables of the horizontal and vertical F-v profile suggest that the ability to develop horizontal power during sprinting is related with the ability of lower limbs to develop vertical power in the concentric and ballistic extension motion, as assessed during jumping tasks, reflecting the lower limb neuromuscular properties. Moreover, the association in V_0 for both tasks, suggest that the capability to produce horizontal force at high contraction velocities is partly related with the capability to produce vertical force at extension velocities. The negative very large relationship between the variables of acceleration performance with the jumping tests (time to 15-m, SJ height) shows that both tests could be predictors towards to performance maximization. However, the remaining variables derived from the F-v testing procedure (F_0 and *F-v slope*) were not significantly related between both tasks. The absence of significant correlations for the F_0 implies that the initial push onto the ground in the horizontal direction, during sprint acceleration is not related with the maximal concentric force output that the athlete's lower limbs can produce during ballistic push-off. The latter may be more explained by the differences in the effectiveness of force application during sprinting and less by the capability of the neuromuscular system to produce total force as assessed through the jumping task (Morin et al., 2012). Furthermore, the absence of associations of the *F-v slopes* between both tasks indicates that the athletes' profile orientation (force or velocity) observed in one task is not necessarily presented in the other one. It also suggests that both tests should be performed in order to ensure a more specific, accurate and comprehensive characterization of high-level athletes' physical qualities in order to design appropriate training programs. Additionally, the magnitude of the correlations for the mechanical variables of both testing procedures indicates that force and velocity capabilities in sprint acceleration are independent and do not refer to the same lower limb muscle force production capacities and effectiveness of force application as in the ballistic push-off movements (Morin and Samozino, 2016). It also should be noted that SJ test is a solely concentric action whereas sprint running involves both eccentric and concentric muscle actions. These results are in line with previous studies suggesting that different neuromuscular factors seem to underpin the performance during sprinting and jumping tasks and thus, both testing procedures should be performed in order to gain a deeper insight into the maximal mechanical properties and function of the lower-body muscles (Jiménez-Reyes et al., 2018; Marcote-Pequeño et al., 2019).

CONCLUSION: Very large correlations between the jumping and sprinting tasks were observed for P_{max} and the performance variables (time to 15-m and SJ height), large correlations were observed for V_0 and non-significant correlations were observed for F_0 and *F-v slope*. The results of this study support that sprinting and jumping are independent skills and both testing procedures, based on the F-v relationship, should be performed to gain a deeper insight into the maximal mechanical properties and function of the lower-body muscles, in high-level sprinters.

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