The Correlation of Force-Velocity-Power relationship of a whole-body movement with 20 m and 60 m sprint performance.

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Abstract

Sprinting ability is of paramount importance for successful performance in sports. The main aim of this study was to examine the correlation between force-velocity-power relationship of a whole-body movement and sprint performance (20 and 60 m sprint time (t_{20} and t_{60}) and maximum sprint velocity (V_{max}). Twelve male participants performed maximal squat jumps with additional loads ranging from 0 to 100 % body weight to obtain force-velocity profiles. The mean force and velocity were calculated during the push-off phase for each jump, which resulted in a force-velocity curve. The theoretical maximal force (F_0), theoretical maximal velocity (V_0) and theoretical maximum power (P_0) were computed via extrapolation of the force and velocity data. In the second session, participants performed two 60 m sprints and the time to cover t_{20}, t_{60} and V_{max} were calculated from the best 60 m trial. Correlation analyses revealed strong and significant correlations between V_0 and t_{20} (r =-0.60), V_0 and t_{60} (r =-0.60), P_0 and t_{20} (r =-0.75), P_0 and t_{60} (r =-0.78). Multiple linear regression indicated that P_0 explained 56%, 61%, 60% of the variability in t_{20}, t_{60} and V_{max} respectively. Our results emphasize the importance of developing power production capabilities to improve sprint performance.

Keywords

Force-velocity, power, sprint, squat jump, regression

Introduction

The ability of skeletal muscles to generate force at difference contraction velocities is explained by the force-velocity (F-V) relationship. Research in this area is diverse and can be divided into single muscle fibre, single-joint and multi-joint studies as it has been reported that the F-V relationship alters depending upon the amount of joints involved in a movement (Cuk et al., 2014). In-vitro studies have revealed a hyperbolic F-V relationship from the studies of Hill (1938) and Fenn and Marsh (1935) for a single muscle fibre, whereby peak power is achieved at approximately 33% of peak contraction velocity. Hill (1938) observed that when the resistance against the muscle decreased, contraction velocity increased, which was depicted by a concave (upward) curve (Wilkie et al., 1949).

Researchers have also tried to understand the F-V relationship during single joint tasks. It has been reported that the F-V and torque-angular velocity plots have an identical shape as that of Hill type curves (Johansson et al., 1987; Leedham and Dowling 1995; Seger and Thorstensson 2000). The findings from previous research also indicate that the power-velocity (P-V) relationship is parabolic (Bosco and Komi, 1979; Epstein and Herzog, 1998), whereby theoretical peak power (P_0) is observed at approximately 33% of maximal shortening velocity. However, this is not necessarily the case during multi-joint movements due to the involvement of multiple muscle groups and tendons.

The multi-joint tasks involve more than one joint during the movement, which are more relatable to sporting and daily activities thus, it can be argued that the results of multi-joint movements are more ecologically valid when the intention is to improve athletic performance. Unlike the hyperbolic curve obtained for single muscle fibre and single joint in previous studies, multi-joint studies involving movements such as leg push-offs (Yamauchi & Ishii 2007; Yamauchi et al., 2005; Samozino et al., 2012), vertical jumping (Cuk et al., 2014), squatting, squat jumping (Samozino et al., 2014a), rowing (Sprague et al., 2007), leg and arm pedalling (Nikoladis 2012), and wheelchair pushing (Hintzy et al., 2003) have reported linear F-V relationships. Since a lot of sporting movements involve coordinated functioning of more than one joint, it is of paramount importance to have a good understanding of the F-V characteristics of multi-joint tasks for designing and implementing testing and training, as well as rehabilitation protocols in the athletic and general population.

The findings from the available literature have demonstrated that an optimal balance exists between force and velocity (Samozino et al., 2014), hence, a better understanding of the F-V relationship for a given level of functional performance can aid in quantifying the performance of an athlete. As multi-joint studies have revealed a linear relationship between force and velocity, it would seem apparent that in order to apply this to a real-world sporting scenario, multi-joint F-V relationships should be used and research should shift away from the theoretical underpinning of single fibre F-V relationships. The linear F-V relationship not only simplifies its assessment from different types of functional tasks, but it also exhibits the capability of the tested muscles to generate high force, velocity and power output (Zivkovic et al., 2017). The F-V relationship can be derived from multi-joint tasks performed under different loading conditions.

A great deal of effort has been applied for determining the physical capabilities which are strongly associated with maximum sprinting velocity due to the importance of sprint performance in sports (Loturco et al., 2015a). The ability of athletes to generate high amount of ground reaction forces in the horizontal direction are positively correlated to sprint performance in the acceleration phase ($r = 0.62$; $p<0.05$) (Mero 1988) and in 100 m sprints ($r = 0.834$; $p<0.01$) (Morin et al., 2012). Previously, studies have attempted to determine the possible predictors of sprint performance by using tests based on strength and power parameters obtained from vertical and horizontal jumping assessment. For instance, in a recent study by Nagahara and colleagues (2014), a significant relationship was found between squat jump performance and 60 m sprint performance. Furthermore, acceleration was significantly correlated with squat jump performance from the 6th to the 10th steps (r=0.48-51), indicating that for effective acceleration, the explosive capabilities required to perform a squat jump are important. A study by Yamauchi and Ishii (2007) examined the correlation between the F-V relationship and vertical jump performance in young and elderly women, revealing that the maximum velocity under zero load (V_0), maximum isometric force and maximum power output (P_0) were positively correlated with vertical jump performance ($r=0.68$, 0.48 and 0.76, respectively; $p<0.001$). A study by Chelly et al. (2010) examined junior soccer players, reporting that 5 m sprint performance was significantly correlated to squat jump absolute power ($r=0.45$; $p <0.05$), squat jump force ($r=0.56$; $p<0.05$) and maximum pedalling force ($r= 0.46$, $p<0.05$) in a cycle ergometer test, indicating that there is a cross-over between jumping performance and sprinting performance, despite being performed in different planes of motion.

The mechanical capabilities of the lower limb neuromuscular system have been well explained by a negative linear F-V relationship and parabolic P-V relationship during several multi-joint tasks (Bosco et al., 1995; Rahmani et al., 2001; Samozino et al., 2007; Yamauchi & Ishii 2007). These relationships represent the power output with increasing movement velocity and change in force output, which may be recapitulated by three variables (F_0, V_0 and P_0). These three parameters represent the mechanical capability of the lower limb to generate external force, velocity and power (Samozino et al., 2012). Several studies have depicted high level of reliability of these three parameters in movements such as bench press (ICC>0.74), countermovement jump (ICC>0.85), and squat jump (ICC>0.91) (Cuk et al., 2014; Ramos et al., 2016), hence, these methods were deemed acceptable to use in the present study.

The studies available in the current literature have tried to link the F-V relationships during several functional movements (countermovement jump [CMJ], cycle ergometer, squat, vertical jump, etc.) with sprint performance. However, there is paucity in the current literature linking the F-V relationship obtained from a whole-body movement with sprint performance. Therefore, using the above theoretical approach, the aim of this study was to examine the relationship between F-V and P-V profiles with sprint performance (20 m sprint time [t_{20}], 60 m sprint time [t_{60}] and maximum sprint velocity [V_{max}]) obtained from a multi-joint movement. The secondary aim of this study was to determine the relationship between the F_0, P_0 and V_0 with sprint performance. It was hypothesised that there would be a strong correlation between the performance variables (F_0, V_0, P_0) and sprint performance.

Method

Participants

A statistical power analysis was performed for sample size estimation. The effect size (ES) in this study was determined using GPower software (Version 3.1) by calculating the coefficient of determination (R^2 >0.5) values reported in previous studies (Loturco et al., 2017; Wisloff et al., 2004), with an alpha = .05 and power = 0.80, the projected sample size needed with this effect size was found to be 9 for the simplest correlational analysis. Therefore, twelve healthy, recreationally active male participants were recruited in this study (age: 22.4 ± 2.2 years; body mass: 81.4 ± 12.0 kg; stature: 1.8 ± 0.1 m). All the participants were informed about the testing procedures and were asked to provide written consent. The study was approved by the ethical committee of Loughborough University and was conducted in accordance with The Declaration of Helsinki. All participants were in good health and were free of any musculoskeletal injuries during the data collection process and were actively involved in sports such as soccer, rugby and track and field events, which involved maximal and sub-maximal sprinting tasks. The participants stature was measured using a digital measuring station (Seca 284, Hamburg, Germany) and body mass was calculated by dividing the mean force acquired from the static trial by “g” (acceleration due to gravity, 9.81 m/s) to report the body weight in kg.

Procedures

The data were collected in three separate sessions. The first session was the familiarisation session in which the participants were provided instructions on how to perform squat jumps. The participants were asked to perform loaded and unloaded squat jumps for data collection during the second session. The participant practised the squat jump in-order to avoid any countermovement during the main trial. Squat jumps were performed on a force plate **(**Kistler Instrument Co-corporation, Winterthur, Switzerland**)** operating at a frequency of 2000 Hz. These devices were interfaced with an analog-to-digital converter **(**Biopac System Inc, Santa Barbara, CA, USA**)** connected to a PC, the Kistler BioWare software (Version 5.1.3.0) was used for data acquisition from the force plates. The participants were asked to stand still on the force plate in order to calculate their bodyweight. After 5-10 minutes of self-selected warm-up, participants were asked to perform maximal squat jumps under different loading conditions (0, 25, 50, 75 and 100% of bodyweight) with an Olympic free-weight barbell placed upon the shoulder region during the loaded trials. A squat rack (Bodymax CF315, Powerhouse fitness Glasgow, United Kingdom) was kept near the force plate to assist the participants while loading and unloading the barbell. The squat jump was initiated with a downward movement to reach ~90° flexion (180° = full extension [Figure 1]). Participants were asked to maintain this position for 1-2 seconds followed by the application of force as quickly as possible to perform a maximal jump. Participants were instructed to keep a constant downward pressure on the barbell to prevent it lifting from the shoulders during the jump. Any countermovement was restricted and was visually checked from the force-time graph obtained from the force plate data. If any of the above conditions were not met, the trial was performed again. Sagittal plane videography (PowerShot SX430 IS, Canon, Canon Electronics Inc., Tokyo, Japan) was used to ensure that the squat jump was performed correctly and was initiated from 90° knee flexion, operating at 25 Hz. A 3-min rest period was administered between the changing of loads.

The F-V relationship was derived from multi-joint tasks performed under different loading conditions. Therefore, the data obtained was modelled by the linear regression model (Cuk et al., 2014).

$$\mathrm{F(V)} = F_0 - \mathrm{a}V \qquad \text{- (1)}$$

where F_0 is the F-intercept representing the maximum force, and “a” is the relationship slope that is represented by F_0/V_0. V_0 is a V intercept at zero F. Further, the P-V relationship was obtained from above equation 1 (Cuk et al., 2014):

$$\mathrm{P(V)} = F(V)\,V = F_0V - a\,V^2 \qquad \text{- (2)}$$

Therefore, the P_0 for each participant was calculated as (Cuk et al., 2014):

$$\mathrm{P}_0 = \frac{F_0 \cdot V_0}{4} \qquad \text{- (3)}$$

where P_0 occurs at 0.5 times the maximum velocity ($V_0/2$) and 0.5 times the external load ($F_0/2$) in the given testing protocol for maximum performance movement.

For each participant, the vertical force component was used to calculate the instantaneous acceleration of the centre of mass (Samozino et al., 2008) using:

$$a(t) = \frac{GRF(t)}{m} - g \qquad - (4)$$

where, "m" is the total mass in kg, GRF is the ground reaction force.

Instantaneous vertical velocity (V) was obtained during the push-off phase by the integration of the acceleration (**a**) over time (t [Giroux et al., 2014]):

$$V = \int_0^t a . dt + V_0 \qquad - (5)$$

As the jump initiates with the period of immobility ($V_0 = 0$) and at each instant the power was then calculated as the product of force and velocity ($P = F \cdot V$).

For each trial, the mean force, velocity and power were calculated by calculating the average force, velocity and power respectively during the entire push-off phase. The push-off phase began when the force value increased and ended when the force value became zero. As the jumping performance is directly associated to force normalised to mass (Samozino et al., 2010), the force values were normalised to participant's body mass for the purpose of analysis in this study (N/kg). From the F and V values during the push-off phase, a linear F-V relationship was established for each participant by least square linear regression (Yamauchi & Ishii 2007; Samozino et al., 2012), which resulted in a line of best fit for corresponding mean force and velocity values. The line obtained was then extrapolated to obtain F_0 (extrapolated intercept at force axis when velocity is zero) and V_0 (extrapolated intercept at velocity axis when force is zero) that a lower limb can produce under zero load (Vandewalle et al., 1987; Samozino et al., 2012). The corresponding P_0 was computed from equation 3 (Vandewalle et al., 1987; Samozino et al., 2012). The data collected was used to obtain F-V relationship and to predict F_0, V_0 and P_0.

Sprint data were collected during the third session on a synthetic track at the High-Performance Athletic Centre (HiPAC), Loughborough University, UK, whereby participants performed two 60 m sprints with a rest time of 8 minutes between the sprints. With regards to the selection of distance for the sprint, it is generally accepted that the initial 20 m is the acceleration phase and peak velocity is achieved between 50-80 m (Healy et al., 2019). The participants performed 5-10 mins of self-selected warm-up prior to the sprint session. A laser displacement device (LDM-300C, Jenoptik, Germany operating at 100 Hz was placed on a tripod stand at an approximate height of 1 m and positioned at 10 m behind the start line. The exact distance of the laser displacement device (LDM) from the start line was determined by taking a static trial of an object prior to each session to obtain the reference distance of 0 m from the start line. Each sprint began with a standing start by following standard commands "1, 2, 3, GO!". LDM data were collected manually upon the "GO!" command. The device was aimed at the participant's lumbar region. All data processing of the LDM device data was conducted using MATLAB™ (version R2018a, The MathWorks™, USA). All participants were instructed to start from a crouch position (staggered stance). A high-speed video camera operating at 240 Hz (Casio Exilim, Tokyo, Japan) was mounted on the tripod and was placed 5 m parallel to running track (starting line). LDM sprint data were collected using Distance Evaluation Sport Software (DAS3E Version 4.0) with a smoothed 51-point moving average filter. The fastest 60 m trial was used for further analyses.

The data obtained from the LDM device were fitted with a fifth-order polynomial function in order to reduce fluctuations in velocity-time profiles due to both inherent noise and within-step fluctuations (Bezodis et al., 2012). A fifth-order polynomial function was chosen to provide the best fit for the displacement-time profile (Bezodis et al., 2010). The polynomial start point was selected from where the raw displacement data values began to increase and the corresponding time to t_{20} and t_{60} was calculated. The fifth-order polynomial function was differentiated with respect to time to obtain a fourth-order polynomial function, which represented the velocity-time profile and thus, V_{max} was calculated.

Insert Figure 1

Statistical Analyses

All data are presented as mean ± SD; the level of statistical significance was set at $\alpha = 0.05$ for every statistical analysis procedure. To determine the degree of linear relationship of performance variables (F_0, V_0, P_0) with sprint performance, Pearson's product-moment correlations were conducted. The Pearson's correlation was found to be sensitive to effects of $r= 0.61$ using GPower software (alpha=0.05; Power=0.80; one-tailed). Based on the evidence available in the existing literature regarding the correlation between strength, power and sprint performance parameters (Cronin et al., 2005; Loturco et al., 2017; Wisloff et al., 2004), where it has been reported that there is a positive influence of the above-mentioned parameters on sprint performance, a one-tailed approach was deemed suitable for our study. The strength of correlation coefficient (r) values were defined as follows: strong (>0.5), moderate (0.3 - 0.49), weak (0.1-0.29) and trivial (<0.1) (Cohen, 1988). The performance parameters for sprint were t_{20}, t_{60} and V_{max}. To investigate the individual linear relationship of F_0, V_0, and P_0 on sprint performance, a multiple linear regression analysis was performed with sprint time to reach 20 m, 60 m and maximum sprint as dependent variables and F_0, V_0, P_0 as independent variables/predictor variables. Therefore, three multiple linear regression models were obtained with t_{20}, t_{60}, V_{max} individually as the dependent variable and the stepwise entry method was chosen in SPSS for three predictor variables in the regression models to find out which of the three predictor variables (F_0, V_0, P_0) was the significant predictor of sprint performance. Shapiro-Wilk tests confirmed that all data were normally distributed for all dependant and independent variables ($P > 0.05$).

Results

The F-V curve for a single participant has been shown in Figure 2. These individual relationships were well fitted by linear regressions ($r^2 = 0.75 – 1.00$; $p < 0.05$).

Insert Table 1

Insert Figure 2

The F_0 showed a moderate negative correlation with t_{20} and was found to be statistically non-significant (Table 2). A non-significant strong negative correlation was displayed between F_0 and t_{60} (Table 2). Furthermore, F_0 had a strong positive correlation with V_{max} and was found to be statistically non-significant (Table 2).

Insert Table 2

The V_0 had a strong negative correlation with t_{20} (Table 2) and was also found to be have a strong negative correlation with t_{60} (Table 2). However, V_0 showed a significant strong correlation with V_{max} (Table 2).

Insert Table 3

The P_0 displayed a significant, strong negative correlation with t_{20} (Table 2), t_{60} (Table 2) alongside a significantly strong positive correlation with V_{max} (Table 2).

Therefore, considering the simple correlation analyses, the sprint performance variables (t_{20}, t_{60} and V_{max}) were significantly correlated to V_0 and P_0, but non-significantly correlated with F_0 as shown in Table 2.

Insert Table 4

Further multiple linear regression model indicated, when considering the three predictor variables (F_0, V_0, P_0) to predict 20 m and 60 m sprint performance, P_0 accounts for a significant amount of sprint performance variability (Table 3 and 4).

Similarly, multiple regression model for prediction of V_{max} revealed that when considering the three predictor variables together (F_0, V_0, P_0) only P_0 accounted for the significant amount of sprint performance variability (Table 5). It should be noted that of the three predictor variables (F_0, V_0, P_0), F_0 and V_0 were excluded in all the three regression models as their contribution for the prediction of sprint performance was non-significant.

Insert Table 5

Discussion and Implications

The results of this study, outlined in Table 2 confirmed the hypothesis that there is a strong correlation between the performance variables (V_0, P_0) obtained from a whole-body movement (squat jump) and sprint performance. The F_0 showed some degree (moderate to weak) of correlation with t_{20}, t_{60} and V_{max}, but the correlation was non- significant (Table 2). There has been no previous studies that has examined the F-V relationship of a whole-body movement with t_{20}, t_{60}, and V_{max}. Therefore, the results from our study will be useful in optimizing athletic performance, taking into consideration the contribution of force, velocity power characteristics to sprint performance variables (t_{20}, t_{60}, V_{max}).

The correlation of F_0 with t_{20} (r = -0.46) was found to be non-significant and moderate, the correlation of F_0 with t_{60} (r = -0.51), and V_{max} (r = 0.52) was found to be non-significant and strong in our study. There have been several studies that have reported the correlation between strength measures and sprint performance. A study by Marcote-Pequeno and colleagues (2019) also reported a non-significant correlation (r=0.09) between F_0 and sprinting performance. There have been no previous studies that have examined the F-V relationship of a whole-body movement with t_{20}, t_{60}, and V_{max}. Therefore, further research is required to confirm the relationship between F_0 and sprint performance variables given the limited research available in this topic. Moreover, a study by Costill et al. (1968) found that strength measures had no relationship with 40-yard dash performance in college football athletes (Costill et al., 1968). The squat was reported to have the lowest correlation (r=0.20) with sprint performance in this study. A non-significant correlation (r=0.3) was also reported between 1 repetition maximum (RM) squat and 40 m sprint performance by Wilson et al., 1996. This could be in part due to the differences in the velocity/acceleration profiles of activities such as squats from sprint-type motion (Cronin and Hansen, 2005). Moreover, in a recent study by Loturco and colleagues (2015a), weak correlation (r=0.261 to 0.272) between squat jump peak force and sprint performance was also reported. Even though force production might play a crucial role during a short-distance sprint such as 5 m or 10 m (Chelley et al., 2010), its contribution for 20 m and 60 m requires further research for better understanding of this topic.

The P_0 also depicted a strong and significant correlation with t_{20} (r = -0.75), t_{60} (r = -0.78) and V_{max} (r = 0.77), indicating that the ability to produce maximal power is a strong determinant of sprint performance. Our results support the findings of Cronin and Hanson (2005) in which significant correlations (r=-0.43 to -0.55) between squat jump height, power output and sprint performance were reported. However, our findings differ from the results reported by Baker and Nance (1999), whereby no significant relationships between relative average power outputs for loaded jump squats of 40, 60, 80 and 100 kg and 10 m and 40 m sprint times were reported. However, when Baker and Nance expressed the power outputs in term so of body mass, a significant relationship was obtained between all power outputs and 10 m and 40 m sprint performance (r= -0.52 to -0.75). Moreover, it is worth noting that there are several apparent differences between the current study and the studies in the above-mentioned literature. For instance, the study performed by Baker and Nance (1999) used a smith machine which allows only vertical displacement of the bar whereas an Olympic free-weight barbell was used in our study, which allowed both vertical and horizontal displacement of the bar with load that in turn contributed to greater trunk extension during the concentric phase of the jump. Additionally, the maximum power was computed from the F-V relationship, obtained from the squat jumps as opposed to power data being differentiated from displacement data. Therefore, it can be argued that power output is a strong determinant of sprinting performance and should be emphasized while training athletes.

A strong and positive correlation was found between P_0 and V_{max} ($r = 0.77$), V_0 and V_{max} ($r = 0.59$) in our study. The findings of this study further support the fact that V_{max} is associated with power and velocity producing capabilities. It can be observed that the correlation between P_0, V_0 with t_{20}, t_{60} was stronger from 20 m to 60 m, revealing that for better sprint times, maximal velocity and power production capabilities are critically important. Also, it has been observed that the high velocity training (increase of jump squat bar velocity) favours the adaptation in high-velocity/low-force end of the force velocity curve (Loturco et al., 2015b). Therefore, it can be inferred that power and velocity should be the main parameters that needs to be targeted during the training sessions by the athletes for optimizing sprinting performance.

Since power is a combination of both force and velocity, the correlation between P_0 and sprint performance parameters (t_{20}, t_{60}, V_{max}) largely depend upon the correlation between V_0 and sprint performance parameters, which can be seen from the simple correlations (Table 2). Further, the multiple linear regression models with F_0, V_0, P_0 as the predictor variables revealed that P_0 accounted for the significant amount of sprint performance. In the first and second multiple linear regression model (Table 3 and Table 4) for prediction 20 m and 60 m sprint performance showed that the ability to produce maximal power is associated with better sprint times. The third model showed that the maximal sprint velocity is largely determined by maximal power producing capabilities. It can be seen from Table 3 and Table 4, multiple regression analysis determined that 56 % and 61% of the variation in 20 m sprint time/sprint performance, 60 m sprint time/sprint performance, respectively, could be explained by the variation in lower limb maximal power capabilities. The third regression analysis (Table 5) determined that 60% of the variation in V_{max} could be explained by variation in maximal power producing capabilities. These findings provide further insight into the importance of power generation capabilities during movements such as squat jumps and sprinting performance, which should be a key focus of strength and conditioning programmes incorporated by coaches and sports science teams.

This study has a few limitations that should be highlighted. Firstly, our study comprised only of male participants, therefore, further research should be conducted on female participants to account for the influence of sex. However, we believe that the results reported in our study can be used as a reference for recreationally active males, as well as athletes aiming to improve their sprint performance. Secondly, it should also be noted that the sample size of our study was small, and thus, the potential for type 2 errors is high, which may explain the lack of statistically significant findings for some of the variables. Despite the power of statistical tests being limited by a small sample size, there was sufficient data in our study to enable regression to be used to identify the key variables associated with sprint performance. It is recommended the present study should be conducted in a larger population, comprised of males and females to fully explore the influence of force, velocity and power on sprinting performance in further detail. Thirdly, a 60 m sprint may have been too long for some of the participants in our study. Whilst this distance would have been suitable for sprinters, it may be beyond the speed maintenance phase for some of the participants in our who were involved in other sports such as soccer or rugby. Fourthly, the tests included in our study have been found to be reliable in the previous studies (Cuk et al., 2014; Ramos et al., 2016). However, the participants or population may be different and this could affect reliability. Therefore, future studies should conduct reliability analysis based on the participants included in their respective studies.

Conclusion

This study confirms that there is a strong correlation between F-V-Power relationship obtained from a squat jump with sprint performance. Simple correlation analyses revealed that V_0 and P_0 obtained during squat are strongly correlated with the t_{20}, t_{60} and V_{max}. Although F_0 obtained during squat jump depicted a moderate correlation with sprint performance variables (t_{20}, t_{60}, V_{max}), it was found to be statistically non-significant. The results show that velocity and power producing capabilities are important for 20 m and 60 m sprint performance, and presents a notable application in the field of strength and conditioning. It should also be highlighted that velocity obtained during squat jump displayed the strongest correlations with sprint performance, hence, when aiming to enhance power production capabilities, sprint coaches should aim to achieve this via improvements to velocity rather than force.

Study Funding

No source of funding was received for conducting this study or preparation of the manuscript.

Acknowledgement

There are no acknowledgements for this manuscript.

Disclosure Statement

The authors do not declare any conflicts of interest for this manuscript.

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Table 1: Descriptive statistics (Mean ± SD) for all variables

Variables	**Mean ± SD**
F_0 (N/kg)	30.39± 3.45
V_0 (m/s)	2.18 ± 0.61
P_0 (W/kg)	16.53 ± 4.88
t_{20} (Seconds)	3.29 ± 0.23
t_{60} (Seconds)	8.25 ± 0.68
V_{max} (m/s)	8.29 ± 0.83

F_0: theoretical maximum force; V_0: theoretical maximum velocity; P_0: maximum power output; t_{20}: time to 20 m; t_{60}: time to 60 m; V_{max}: maximum sprint velocity

Table 2: Correlation data and significance levels for all variables (N=12)

		95 % confidence intervals		
	r	Lower bound	Upper bound	P
t_{20}				
F_0	-0.46	-0.82	0.15	0.13
V_0	**-0.60**	-0.87	-0.03	**0.04***
P_0	**-0.75**	-0.92	-0.30	**0.005***
t_{60}				
F_0	-0.51	-0.84	0.09	0.09
V_0	**-0.60**	-0.88	-0.05	**0.04***
P_0	**-0.78**	-0.94	-0.38	**0.003***
V_{max}				
F_0	0.52	-0.07	0.84	0.08
V_0	**0.59**	0.02	0.87	**0.04***
P_0	**0.77**	0.36	0.93	**0.003***

F_0: theoretical maximum force; V_0: theoretical maximum velocity; P_0: maximum power output; t_{20}: time to 20 m; t_{60}: time to 60 m; V_{max}: maximum sprint velocity; * $P<0.05$

Table 3: Multiple linear regression analysis for 20m sprint performance predictor variables (t_{20}) (N=12)

Multiple regression model	r^2	SEE (s)	P
	0.56	0.16	<0.001
Independent Variables	Coefficient	T	P
P_0	-0.04	-3.54	<0.001
Constant	3.88	22.37	<0.001

SEE: Standard Error of Estimate; P_0: maximal power output; t_{20}: time to 20 m

Table 4: Multiple linear regression analysis for 60m sprint performance predictor variables (t_{60}) (N=12)

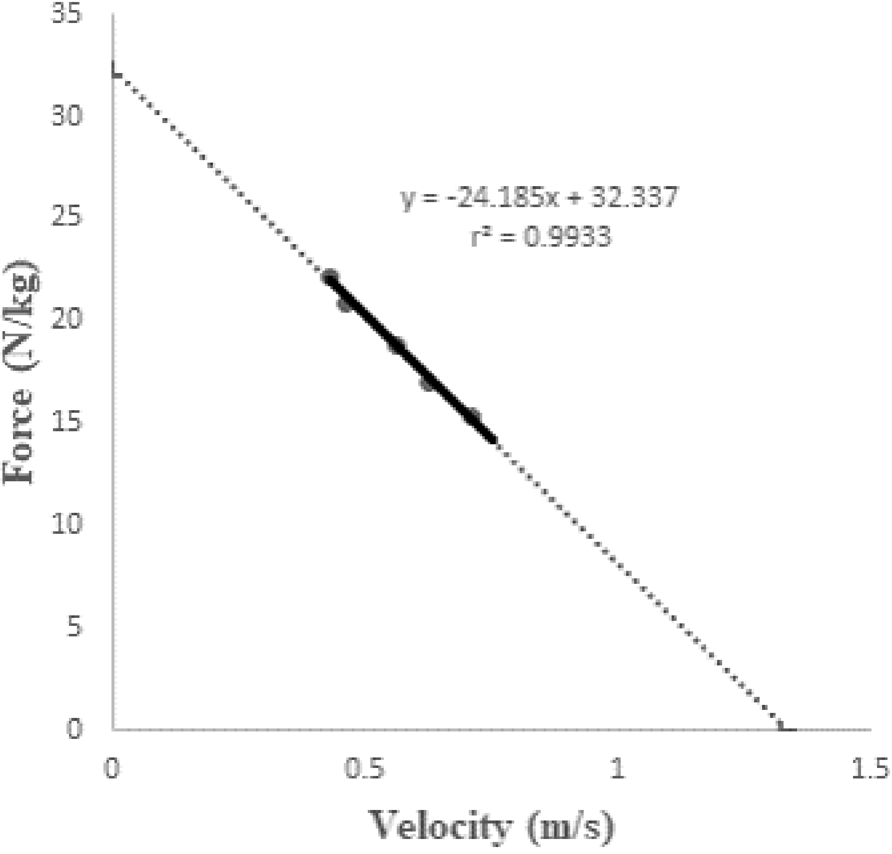
Multiple regression model	r^2	SEE (s)	P
	0.61	0.44	<0.001
Independent Variables	Coefficient	T	P
P_0	-0.11	-3.98	<0.001
Constant	10.05	21.32	<0.001

SEE: Standard Error of Estimate; P_0: maximal power output; t_{60}: time to 60 m

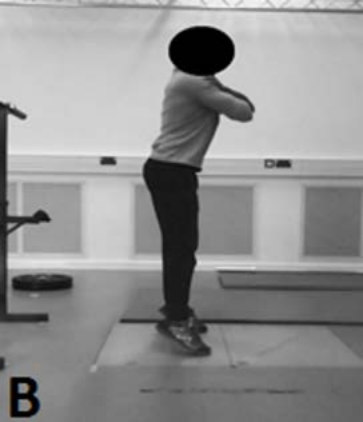
Table 5: Multiple linear regression for the prediction of maximum sprint velocity (V_{max})(N=12)

Multiple regression model	r^2	SEE (m/s)	P
	0.60	0.55	<0.001
Independent Variables	Coefficient	T	P
P_0	0.13	3.84	<0.001
Constant	6.12	10.42	<0.001

SEE: Standard Error of Estimate; P_0: maximal power output; V_{max}: maximum sprint velocity


y = -24.185x + 32.337
r² = 0.9933
Force (N/kg)
Velocity (m/s)
35
30
25
20
15
10
5
0
0
0.5
1
1.5


A


B


C