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ABSTRACT

Explosive actions are integral to soccer performance and highly influenced by the ability to generate maximal power. The purpose of this study was to investigate the relationship between force-velocity profile, jump performance, acceleration and maximal sprint speed in elite female soccer players. Thirty-nine international female soccer players (24.3 ± 4.7 years) performed 40-m sprints, maximal countermovement jumps and five loaded squat jumps at increasing loads to determine individual force-velocity profiles. Theoretical maximal velocity, theoretical maximal force, maximal power output, one repetition maximal back squat and one repetition maximal back squat relative to body mass were determined using the force-velocity profile. Counter movement jump, squat jump and maximal power output demonstrated moderate to large correlation with acceleration and maximal sprint speed (r= -0.32 to -0.44 and -0.32 to -0.67 respectively, $p < 0.05$). Theoretical maximal velocity and force, one repetition maximal and relative back squat demonstrated a trivial to small relationship to acceleration and maximal sprint speed ($p > 0.05$). Vertical force-velocity profiling and maximal strength can provide valuable insight into the neuromuscular qualities of an athlete to individualize training, but the ability to produce force, maximal power, and further transference into sprint performance, must be central to program design.

Key Words: jumping, acceleration, speed, strength, testing,

INTRODUCTION

One of the main physical performance determinants in field-based sports is the ability to produce high mechanical power output during jumping and sprinting [1,2]. This power output depends on the ability of athletes' neuromuscular system to generate high levels of force and produce this force at high contraction velocity. Force and velocity are therefore considered the underpinning features of mechanical power output in sport movements [3,7]. The vertical jump is a commonly used movement to assess force-velocity (F-v) profile and maximal power output (P_{max}) because of its simplicity and ballistic nature [2]. This assessment also allows for the estimation of a 1 repetition maximal (1RM), using the load-velocity relationship, adding to the picture of the athlete profile [4]. While, F-v profiling has been used extensively in various population to understand athletic performance and inform training prescription [5,6], the research and application for international level athletes, especially female soccer players, remain scarce.

When assessing the F-v profile of a player, the transference to on-field performance must be considered. Sprinting have been identified as a differentiating factor in performance between elite and non-elite female soccer players [7,8,9]. An increase in competition level is associated with an increase in sprint distance and density of efforts in female soccer [7,10] and the international game is becoming faster across all measurable aspects [11]. Therefore, assessing the relationship between F-v profile and sprint performance in such population could provide insight into the validity of the profile while also define possible underlying determinants of sprint performance in elite female soccer players [12,13]. Sprinting ability can be divided into acceleration (ACC) and maximal sprint speed (MSS) capacity. Lower-body power, relative and absolute maximal strength (e.g. 1RM back squat) and horizontal force production are all qualities demonstrating a relationship to both ACC and MSS [10,14,15,16,17,18,19]. Proficient ACC for male and females have been linked to concentric movements with a limited stretch shortening cycle (SSC) [13,20], such as the squat jump (SJ) [21] or 1RM [19]. This contrasts with MSS where a closer relation to activities utilizing SSC based qualities (e.g., drop jump or countermovement jump [CMJ]), and the rate at which force can be applied with minimal ground contact time has been observed [8,10,14,19,21]. However, very little has been conducted to define the degree of association of mechanical variables derived from the F-v profile, unloaded jumps and 1RM, to sprint performance in very elite female soccer players [4].

Given the critical role of strength, power and more specifically sprinting in soccer, understanding the mechanical determinants of ACC and MSS is essential for players' assessment and the design of training programs. To address the gaps in the current literature examining female athletes and specifically at the elite level, the aim of this study was to investigate the relationship between vertical F-v profile, estimated 1RM, unloaded jumps, ACC and MSS in elite female soccer players. The current study also had the objective to provide normative values of international standard elite female soccer players for relatively new mechanical and strength variables using the F-v profiling.

METHODS

Participants

Thirty-nine elite female soccer players (24.3 ± 4.7 years, 64.7 ± 6.3 kg, 168.8 ± 6.0 cm), who represented their country throughout the four-year testing window (2012-2016) were recruited for this study. During this period, the team won an Olympic bronze medal in London 2012 and Rio 2016 and was ranked between 4th and 7th in the world [22]. Only outfield players were included in the study: midfielders (n = 9), full back (n = 9), center back (n = 7) and forwards (n = 14). This study was approved by XXXX research ethics committee and conformed to the recommendation of the declaration of Helsinki. This study meets the ethical standards of the International Journal of Sports Medicine [23].

Experimental Design

Testing was supervised seven times by the same Certified Strength and Conditioning Specialist at the same location over a four-year time period. Testing data where the best 40-m sprint was performed was selected for this cross-sectional study and considered the peak performance across testing occasions when players completed the testing battery on multiple occasions. All testing was conducted in an indoor facility maintained at standard environmental conditions (21˚C). Testing took place in the morning after a minimum one-day rest period and following a tapering period for optimal performance. Following a standardized 25- minute warm-up, sprint testing was conducted first. Following a 1-3-hour break to manage fatigue, the CMJ and F-v jump testing were completed. Prior to testing, the athletes body mass (Seca 874, Hamburg, Germany) was measured to nearest 0.1 kg and leg length was measured to nearest 0.1 cm by the same athletic therapist throughout all testing sessions. Leg length was measured with the athlete on the ground in a supine position with the toes plantarflexed with the distance between the anterior iliac spine and the big toe retained [9].

Sprint Testing

Sprint testing was conducted on a wooden gymnasium floor over 40-m with timing gates (Swift SpeedLight, SwiftPerformance, Wacol, Australia) at 0-m, 10-m, 30-m and 40-m, split times were recorded to the nearest 0.01s. Players initiated the sprint when ready from a split standing position 0.3-m behind the first timing gate. Each athlete had three attempts, with a 3-min recovery between trials. The average of the best two trials was used for analysis. The 10-m sprint time was defined as the ACC, and the 30-m - 40-m split time as the MSS.

Countermovement Jump

Following sprint testing and prior to the squat jumps, each participant completed three unloaded countermovement jumps. Starting from a standing position, athletes squatted dynamically to a self-selected depth before initiating the jump. A 2-min recovery was given between jumps to minimize fatigue. Athletes completed three attempts with the average of the two best trials utilized for analysis. Jump height was measure with a jump mat (Swift EZEJump, SwiftPerformance, Wacol, Australia) and to reduce the error in flight time estimation, landing was standardized to a plantar flexed position. The typical error in the unloaded jumps in our cohort were 0.01 m (SJ), and 0.01 m (CMJ; *unpublished data*).

Force-Velocity Profile

F-v testing took place inside a squat rack, elastic bands were placed at a depth that was self-selected at the bottom of the squat position to ensure no countermovement was completed and the athlete started the SJ at the same depth every jump. Height of the iliac crest, was measured at the bottom position of the squat with the difference between leg length and squat depth height deemed to be the center of mass displacement during the push-off phase (h_{PO}) [24]. All players completed concentric only squat jumps at five different loads (0, 11.3, 22.6, 34.0 and 45.3 kg). Load order was not randomized for timeliness of testing large groups. Athletes completed three attempts (15 jumps total) at each load with the best performance of each load utilized for analysis. The same jump mat and landing technique to the CMJ testing was utilized for measurements. From the incremental load jumping protocol, the vertical F-v profile was calculated using the method of Samozino et al. [25]. Using a custom spreadsheet, the regression line between force and velocity across the load spectrum was plotted [26]. Force–velocity relationships were determined by least-squares linear regressions using average force and velocity at each load and individual force–velocity slopes were extrapolated ($R^2 = 0.94 \pm 0.05$) to obtain for each subjects [2,27] (i) The individual slope represented the F-v profile relative to body mass (S_{FV}, slope of the F-v curve, in $N.s.kg^{-1}$); (ii) F_0 and V_0, which corresponded to the intercepts of the force–velocity slope with the force and velocity axes, respectively; (iii) Maximal Power output. From P_{max} and h_{PO} values the theoretical optimal S_{FV}, maximizing jumping performance were computed for each subject using the equation proposed by Samozino et al. [2]. The difference between actual and theoretical maximal jumping performance was then computed and referred to as the F-v imbalance (Fv_{imb}, in % of theoretical maximal jumping performance) [2]. A Fv_{imb} value around 0% indicates a F-v profile equal to 100% of the optimal profile (perfect balance between force and velocity qualities), whereas a F-v profile value higher or lower than the optimal indicates a profile too oriented toward force or velocity capabilities, respectively. For statistical purposes, 100% (i.e. optimal profile) was given a ratio of 1 and anything above or under a 100% was given a ratio representative of that percentage (e.g 60% or 140% given a ratio of 0.6). The F-v profile was also used to calculate 1RM using the estimated load point intercepting the velocity value 0.23 m/s. This method has been previously validated [4,28], as estimated 1RM and actual 1RM have been found to be highly correlated (R^2 0.95–0.96) [4]. One RM was also expressed relative to body mass and referred as relative 1RM.

Statistical Analysis

Data in the text and figures are presented as means with 90% confidence Limits (CL). Variables were assessed for normality via the Shapiro-Wilk test. Normally distributed mechanical and sprint performance results were tested through Pearson's correlation coefficients. In instances of non-normally distributed data, the Spearman rank test was used. Statistical significance was set at an alpha level size to $p < 0.05$ for all measured variables. In order to interpret the degree of relationships between variables the following criteria was employed (r, 90% CL): < 0.1, trivial; 0.1, small; 0.3, moderate; 0.5, large; 0.7, very large and 0.9, extremely large. If the 90% CL overlapped small positive and negative values, the magnitude was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude [29].

RESULTS

Table 1 displays the performance and mechanical variables utilized in this study. The Load-velocity relationship and predicted 1RM are displayed in Figure 1. Following correlation analysis, ACC and MSS demonstrated a very large correlation ($r = 0.71$, CL 0.55 to 0.82, $p < 0.01$). All correlations between jump, strength and sprint variables are presented in Figure 2. V_0, P_{Max}, unloaded SJ and CMJ demonstrated a small to moderate correlation with ACC. F_0, P_{Max}, relative 1-RM, unloaded SJ and CMJ demonstrated a small to moderate relationship to MSS. Similar to ACC, the CMJ demonstrated the strongest relationship to MSS ($r = -0.67$, CL -0.80 to -0.50). The FV_{imb} of the players were on average 8 ± 34% from their optimal profile, a bias towards force orientation (i.e. 108%) [6]. Having close to an optimal vertical F-v profile, expressed by the Fv_{imb}, did not appear to be related to sprint performance ($r = 0.03$, CL -0.24 to 0.29 and $r = -0.07$, CL -0.33 to 0.20 for ACC and MSS, respectively).

Insert Table 1 about here

Insert Figures 1 and 2 about here

DISCUSSION

This study's aim was to investigate the relationship between squat jump F-v profiles, estimated 1RM, unloaded jumps, ACC and MSS in elite female soccer players. At the highest level, players tend to have a well-balanced F-v profile (i.e Fv_{imb}) that optimizes their jump performance. This is particularly relevant as the ability to demonstrate better unloaded jump performance, and further high P_{max} value, appears to be related to sprint performance in elite female soccer players.

ACC results in this study, as expressed as the 0 to 10m split, were in line with previous research while MSS was faster than previously published research on professional and collegiate female soccer players [30,31,32]. This could suggest that MSS may be a better descriptor of elite female soccer players than ACC. The ability to have a higher MSS reserve could contribute to the ability to sustain higher volume of sprinting as well. Match data would suggest so as high speed running density and volume is increasing with the level of play and quality of teams [7,8,11]. ACC and MSS also only demonstrated a shared variance (R^2) of 50%. This finding indicates that, while ACC and MSS are related, they also require different neuromuscular and biomechanical qualities [33]. Buchheit et al. [14], reported similar shared variance between ACC and MSS in elite youth soccer players, suggesting that an improvement in one quality through training may not necessarily lead to a change in the other. Knowing that ACC and MSS are differing, it is important to consider that some players may need to have a greater level of ACC or MSS oriented training due to deficiencies or positional requirements.

The F-v profiling provided an additional outlook on the mechanical properties of the players, potentially allowing to individualize training methods to optimize the profile and future performance [5,6,24]. Marcote-Penqueno et al. [13], and Jimenez-Reyes et al. [12], reported high P_{max} values (27.7 ± 3.7 W·kg^{-1} and 24.7 ± 0.9 W·kg^{-1}, respectively) of elite club female soccer players. These findings are much higher than our data presented for P_{max} (20.6 ± 2.3 W·kg^{-1}). The players tested in the previous literature were also far more velocity dominant when expressed with V0 (3.35 ± 0.59 m·s^{-1} and 3.03 ± 0.33 m·s^{-1}) [13,12] compared to the current study (2.35 ± 0.45 m·s^{-1}), leading to difference in the S_{FV} (-10.4 ± 2.66 N·s·m^{-1}·kg^{-1} and -16.0 ± 4.9 N·s·m^{-1}·kg^{-1}, respectively.) The players in the current study demonstrated less Fv_{imb}, (108 ± 34% - force bias), as compared to the previous research where athletes F-v profile showed a greater Fv_{imb} (65 ± 16% - velocity bias) [12]. The current data suggest that as the level of play increases from club to international standards, players are more balanced to maximize jump height and possibly have a higher level of strength to sustain training volume and match load [34]. However, the large standard deviation in the current study would suggest that some players might still benefit from an individualized approach [5,35,36]. While neither the F-v slope nor the Fv_{imb} were related to sprint performance in the current study, optimizing force and velocity qualities could translate into better unloaded jumping height and P_{max} [5,6,25,36], but also sprinting performances as long as transference from vertical to horizontal force production is emphasized in the training design [6].

As previously demonstrated [8], both the unloaded SJ and CMJ were significantly correlated to sprint performance in the current study. The higher degree of correlation between CMJ and MSS compared to ACC also highlighted the increased contribution of the SSC at top speed [36]. This is in agreement to previous literature where movements, such as the CMJ or bounding utilizing the SSC were significantly correlated to MSS performance [8,37,38]. While previous research investigating F-v profile in female players did not assess CMJ, it demonstrated large (r = -0.60)

[13] to very large (r = -.73) [12] correlations between 20-m sprint time and SJ. Given the 60% shared variance between the SJ and P_{Max}, as well as nearly the exact same relationship to the sprint variables, it can be assumed that in the current population, P_{Max} occurred very close to body mass despite the fact that the power-load relationship was not established. This is in line with previous literature investigating optimal load to produce P_{max} in jumping [37] as well as the maximum dynamic output theory by Jaric and Markovic [39].

The ability to create high levels of force (F_0) or to move faster (V_0) in the current athlete population did not appear to be significantly correlated to sprinting performance. Estimated 1RM, which shared a variance of 92% with F_0 due to the method of its estimation through the load-velocity relationship, did not show a relationship with sprint variables either, while relative strength displayed only small and non-significant correlation to both ACC and MSS. This is in disagreement with both Comfort et al. [16] and Wisloff et al. [18] reporting that maximal back squat strength was significantly related to ACC in male soccer players. However, Cronin et al. [40] have shown that 1RM gain have limited translation to ACC performance. The findings in the current study would reinforce the concept that a well-balanced F-v profile to optimize ballistic performance for a given P_{max} may be the most beneficial to sprint performance. Thus, elite athletes who have years of resistance training experience, may not gain significant benefit in ACC or MSS by getting stronger as compared to less trained individuals [12]. This has implications for elite athlete program design; promoting a balanced program comprised of both strength and velocity tasks, to improve sprint performance, but also other critical areas for female soccer players, like injury prevention [41].

The testing battery spanned across a full Olympic cycle and players were tested multiple times. By choosing the best 40-m sprint time, we considered that players where in top form in one of the most relevant physical metrics of the game. The rest period between sprinting and jumping varied due to logistical constraint with elite athletes and could be considered a limitation. However, we ensured that there was sufficient rest to recover from the sprints (>1h) and a proper priming before the jump performance. During F-v testing, lighter loads were utilized first proceeding to heavier loads for timeliness of testing large groups. This may have encouraged a velocity bias profile as the athletes jumped under a greater level of fatigue with the heavier loads. However, the players tested in the current study still displayed close to an optimal profile and higher F_0 values than in similar population [13].

CONCLUSION

Vertical F-v profiling provides an insight into the mechanical properties that should be developed to improve ballistic performance and the maximal levels of force and velocity of the athlete's neuromuscular system. The current finding showed that on average, elite players tested had a well-balanced profile but that the variance still calls for individualized training design to optimize jump performance. When interpreting the vertical profile, practitioners should not assume a strong relationship to sprinting performance. As SJ and CMJ performance demonstrated the strongest relationship to ACC and MSS performance, optimization of jump height performance or activities requiring maximal lower-limb power output should be practiced. While F_0 and 1RM were not related to sprint performance, practitioners should still ensure a strong underlying base level of strength, as a foundation to the optimization of the F-v profile and P_{max}. The orientation of force production should be a focal point to the programming puzzle to ensure that there is a high level of transference to sprint performance. The integration of a horizontal based profile in combination with the vertical profile could provide a more comprehensive picture of the force transference capabilities of players and an insight into others mechanical variables relevant to sprint performance and program design in this elite athletic population.

TABLE 1: Performance variables of elite female soccer players (N=39).

	Mean ± SD
Maximal Power ($W.kg^{-1}$)	20.6 ± 2.3
Theoretical Maximal Force (N/kg)	35.8 ± 5.2
Theoretical Maximal Velocity (m/s)	2.35 ± 0.45
Force Velocity Slope (N.s/m/kg)	-16.0 ± 4.9
Force-Velocity Imbalance (%)[1]	108 ± 34
Dynamic 1RM (kg @ 0.23m/s)	120 ± 26
Relative 1RM (kg/BM)	1.84 ± 0.34
Squat Jump (cm)	27.1 ± 3.2
Countermovement Jump (cm)	32.3 ± 3.5
ACC: 0-10-m split time (sec)	1.95 ± 0.07
30-m (sec)	4.54 ± 0.15
40-m (sec)	5.79 ± 0.20
MSS: 30-40-m split time (sec)	1.24 ± 0.05

1RM = 1 repetition maximum; ACC = acceleration; MSS = maximal sprint speed;
[1]100% represent an optimal profile, while values under 100% express a force deficit and values above 100% a velocity deficit.

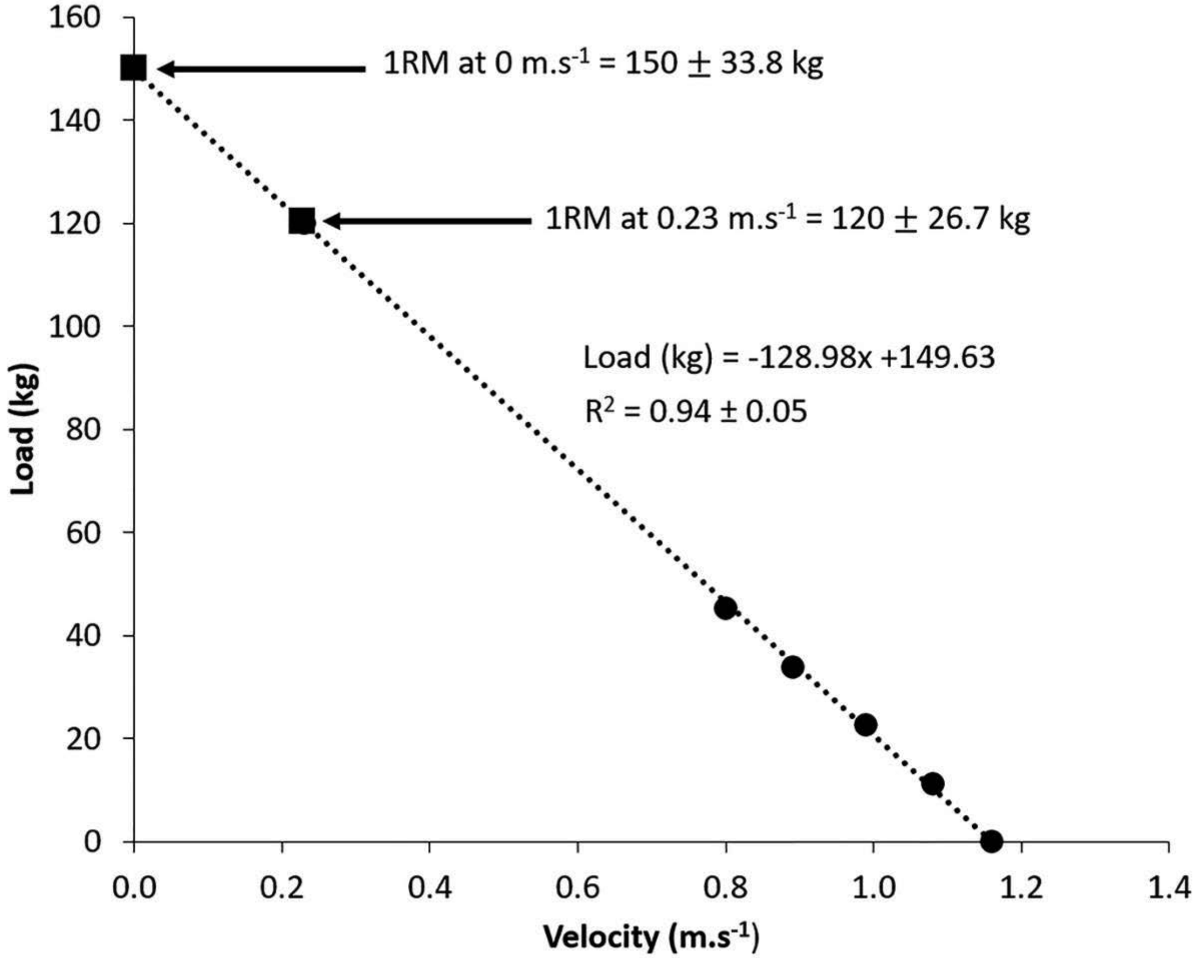

Figure 1: Average velocity-load relationship. Squares represent isometric 1RM (1RM at 0m/s) and dynamic 1RM (1RM at 0.23m/s). Circles represent a squat jump with a standardized additional load.

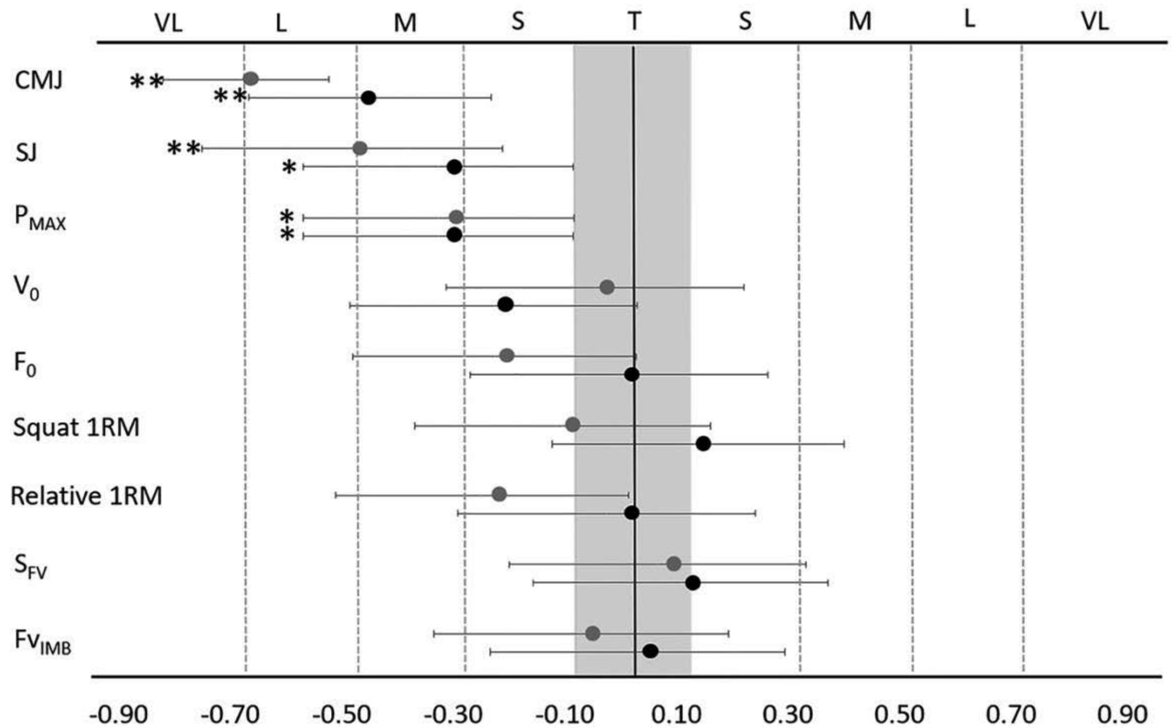

Figure 2: Correlation coefficient (mean and confidence interval set at 90%) between ACC (black circle), MSS (grey circle) and jump derived variables. Trivial (T) (0.0-0.1), Small (S) (0.1-0.3), Moderate (M) (0.3-0.5), Large (L) (0.5-0.7), Very Large (VL) (0.7-0.9). CMJ = countermovement jump; SJ = squat jump; Pmax = maximal power; F0 = theoretical maximal force; V0 = theoretical maximal velocity; 1RM = 1 repetition maximum; SFV = Force-Velocity slope; Fvimb = Force-Velocity Imbalance. The grey area represents trivial correlation coefficients; ($p < 0.05$*; $p < 0.01$**).

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