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Title: Predictors of linear and multidirectional acceleration in elite soccer players

Short title: Linear and multidirectional acceleration predictors

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ABSTRACT

Linear and multidirectional acceleration underpins success in professional soccer match-play. However, the physical qualities that determine these performance indicators are poorly understood in elite players. English Premier League players (n=26) performed isometric mid-thigh pulls (IMTP), bilateral and unilateral drop jumps (DJ; from 40 and 20 cm, respectively), bilateral and unilateral countermovement jumps (CMJ) and assessments of linear (5-, 10-, 20-m) and multidirectional (left/right pre-planned and reactive) acceleration. Regression analyses highlighted that 21% of variance in 5-m sprint time (1.02±0.07 s) was explained by relative peak power output (PPO) in bilateral CMJ (54.5±5.3 $W{\cdot}kg^{-1}$). A 5.4 $W{\cdot}kg^{-1}$ increase in CMJ predicted a 0.03 s decrease in 5-m sprint time (P=0.02). For 10-m sprint time (1.72±0.09 s), 44% of variance was explained by isometric relative peak force (PF; 30.4±4.9 $N{\cdot}kg^{-1}$) and bilateral relative CMJ PPO (54.5±5.3 $W{\cdot}kg^{-1}$). A 5.4 $W{\cdot}kg^{-1}$ increase in CMJ predicted reduced 10-m sprint times by 0.04 s (P=0.01). For 20-m sprint time (2.94±0.11 s), 55% of the total variance was explained by isometric relative PF (30.4±4.9 $N{\cdot}kg^{-1}$) and relative CMJ PPO (54.5±5.3 $W{\cdot}kg^{-1}$). Increases of 5.4 $W{\cdot}kg^{-1}$ in bilateral CMJ predicted an improvement of 20-m sprint time by 0.06 s (P=0.002). Contributions were insignificant (P>0.05) for pre-planned and reactive multidirectional acceleration. Relativized indices, especially those related to force production during CMJ and IMTP tests, likely underpin linear but not multidirectional acceleration performance in professional soccer players. When linear acceleration is a training focus, practitioners should seek to monitor CMJ and IMTP test performance.

Key words: Speed, football, agility, velocity, prediction, sprinting

INTRODUCTION

In soccer match-play, research has consistently highlighted that low intensity activities such as walking and jogging dominate (3, 23) and that players cover 9–14 km per match (4, 24). Conversely, high intensity actions are performed every 70 s (30) and represent between 8-12% of the total match distance covered. Despite the sport being primarily aerobic in nature (3), it is likely that high intensity actions contribute directly to success in soccer. For example, out-pacing or out-maneuvering an opposing player may yield a competitive advantage in team sports (2, 11, 29). Likewise, 83% of goals scored in the first German national league were preceded by at least one powerful action from either the scoring or assisting player (10). Enhanced knowledge of the key physical determinants of elite soccer performance will likely inform training program design such that the underlying performance characteristics of play at the elite level are optimized.

Previous investigations have highlighted that indices of high intensity running discriminated between soccer players of differing performance levels (18). For example, Reilly et al. (21) highlighted that linear sprinting speeds differed by between ~0.03 s and ~0.12 s between elite and sub-elite players over 5 and 15 m, respectively. Likewise, the ability to change direction while sprinting differentiated between elite and sub-elite players as ~1.75 s separated each group in a 40 m sprint test that incorporated pre-planned turns (21). With this in mind, identification of the key qualities that influence linear and multidirectional speed could help to ensure that training practices are personalized and focused upon improving the key qualities that influence performance in a time-efficient manner.

Indices of strength, power, reactive strength and asymmetry have previously been highlighted as predictors of both linear (5, 37) and multidirectional (16, 29, 38) sprint performance. Indeed, faster multidirectional speed performances, greater relative lower body strength, and higher magnitude plant foot kinetics have been observed in stronger versus weaker recreational team sports players (29). Likewise, reactive strength, the ability of the neuromuscular system to tolerate a relatively high stretch load and change from rapid eccentric to rapid concentric movements (36), indicated the strongest relationship to change of direction speed in amateur male athletes (38). However, not all studies have demonstrated such associations, notably, Marcovic (17) observed weak relationships (R=0.03 – 0.44) between indices of leg extensor strength and power, and performance on a number of pre-planned change of direction tests in physical education students. For linear sprinting, Requena et al. (22) reported no relationship between variables derived from isometric mid-thigh pull (IMTP) tests and 15 m sprint time in semi-professional soccer players; data which supports previous findings (34).

Such equivocal findings highlight that further research is warranted to isolate key physical characteristics that underpin linear and multidirectional speed performance. This is especially true in elite athletes who have largely been omitted from such research previously (5, 17, 22, 29, 37, 38). The aim of this study was therefore to examine which variables derived from commonly used assessments such as IMTP, countermovement jumps (CMJ) and drop jumps (DJ) predicted linear and multidirectional speed performances in elite soccer players. This information will likely allow the tailoring of testing batteries and training programs that involve elite soccer players.

METHODS

Experimental approach to the problem

This cross-sectional and observational study investigated relationships between variables collected throughout a typical pre-season testing battery that included IMTP, DJ, CMJ, linear acceleration and multidirectional agility (pre-planned and reactive) tests. Test–retest reliabilities (intraclass correlation coefficient) for peak force (PF), peak rate of force development (PRFD), and maximum jump height were 0.98, 0.89, and 0.98, respectively.

Subjects

Data is presented for 26 professional soccer players (age: 25 ± 4 years, mass: 76.3 ± 8.6 kg, stature: 1.79 ± 0.08 m) competing on behalf of an English Premier League senior team throughout the 2015/2016 season. Data represents only outfield players due to differences in the pre-season testing of goalkeepers and outfield players at the professional club from which players were recruited. The study required players to provide informed consent prior to participation and conformed to the Code of Ethics of the World Medical Association (approved by the ethics advisory board of Swansea University). All players were considered healthy and injury-free at the time of the study and were in the pre-season phase of their full time training cycle. Participants were recruited on the basis that they had been engaged in a full time professional soccer training program for at least 2 years and were able to complete each of the performance assessments with correct technique.

Procedures

Following habituation of main trial procedures, players presented to the laboratory after having followed a standardized dietary intake as directed by the club's performance nutritionist. The activity in the 48 h period before habituation and main trial testing included a single training session that lasted no longer than 60 min and started at ~10:30 h. These sessions typically required a channel warm-up (including dynamic stretches and short sprints), box drills (e.g., static keep ball, 6 vs 2) and tactical practices to be performed and were characterized as low volume and low intensity. Players were advised to rest in the afternoons following training.

Upon arrival for main trials, and following voiding of bladder and bowels, players performed a ~20 min coach-led warm-up on an indoor synthetic running track that included dynamic stretches and short sprints before a practice attempt at each of the performance tests. A 5 min passive rest period preceded the performance of 3 attempts at each of the testing battery assessments in the order of CMJ (bilateral then unilateral), DJ (bilateral then unilateral), IMTP, linear acceleration (20 m from standing start with 5 and 10 m split) and multidirectional acceleration (pre-planned then reactive). Each attempt was separated by a 5 min recovery period and the coaching team was present throughout testing to encourage maximal effort.

Isometric Mid-Thigh Pull (IMTP)

The IMTP testing was carried out with players standing on a portable force platform (type 92866AA, Kistler Instruments Ltd., Farnborough, United Kingdom), which was centrally positioned on the floor underneath the bar of a power rack. Players assumed a body position similar to that when completing the second pull of a power clean with a flat trunk position and their shoulders in line with the bar; thus maintaining a knee angle of approximately 120–130^0 (checked using a goniometer, Smith & Nephew, Hull, United Kingdom) as per previous research (12, 31, 33). The bar height could be fixed at various heights above the force platform, to accommodate players of different sizes, and the rack was anchored to the floor. Once bar height was established, players stood on the force platform and their hands were strapped to the bar (12, 31, 33). The vertical component of the ground reaction force (GRF) during a maximal effort of the IMTP was measured using the portable force platform with built-in charge amplifier.

A sample rate of 1000 Hz and a vertical force range of 20 kN were used for all trials. The force–time data were recorded on a portable computer using a 16-bit analogue-to-digital converter. A sample length of 10 s was used for all trials, consisting of a pre-trigger phase (a record of the force–time history immediately before the trigger switch was operated) of two seconds, and a post-trigger phase (a record of the force–time history immediately after the trigger switch had been operated; including the IMTP) of eight seconds. The trigger switch simultaneously illuminated a signal lamp to inform the player to commence the pull and players were instructed to pull as hard and as fast as possible for a period of approximately five seconds. These commands were based on previous research indicating that the use of these instructions produces optimal results for PF and PRFD (7).

Analysis of the IMTP data was as per previous methods incorporating elite team sport athletes (33) and required identification of a reliable start time (Ts) using instantaneous rate of change of force with respect to time data calculated from the first derivative of the vertical component of the GRF-time history. After identification of Ts (the instant after the trigger point that the first derivative exceeded the mean value plus five standard deviations; SD), PF was determined as the peak value from the vertical component of the GRF–time history minus the player's body weight. The F100 variable was defined as the absolute value of the vertical component of the GRF minus the player's body weight at 100 ms after Ts. The PRFD was taken as the maximum value of the first derivative of the vertical component of the GRF–time history following Ts.

Countermovement jump testing

Using a portable force platform and CMJ analyses, peak power output (PPO) was determined according to methods described previously (20, 33). The vertical component of the GRF during the CMJ and the player's body mass was used to determine instantaneous velocity and displacement of the player's center of gravity. Instantaneous power output was determined using Equation 1 and the highest value produced was deemed PPO. Values represent peak data derived from three attempts and bilateral and unilateral CMJ attempts were performed separately.

Eq'n 1: Power (W) = vertical GRF (N) x Vertical velocity of center of gravity ($m \cdot s^{-1}$)

Drop jump (DJ) testing

Reactive strength index (RSI) was measured via the use of DJ from a plyometric box (20 and 40 cm for unilateral and bilateral attempts, respectively) onto a portable force platform. In order to minimize the influence of arm swing, hands were required to be placed on the hips during the movement. When instructed, players stepped off the box, landed and then jumped as high as possible before landing back on the force platform. Players were instructed to minimize ground contact time while seeking to maximize jump height. Equation 2 presents how RSI was calculated and DJ stiffness was calculated as peak vertical force (ignoring any initial impact peak) divided by the vertical displacement of the center of mass (26). Displacement of the center of mass between touchdown and the lowest point was determined from double integration of the vertical acceleration data (8) with vertical velocity assumed to be zero halfway through the flight phase following ground contact. Bilateral and unilateral DJ were performed separately. Values represent peak data derived from three attempts.

Eq'n 2: Reactive strength index (RSI) = Flight time (FT) / Contact time (CT)

Where FT is the time interval between toe-off and landing and CT represents time difference between first contact and toe-off

Linear acceleration testing

The time taken to cover a distance of 20 m from a stationary start was used as the measure of linear acceleration. Players started in a 2-point crouched position with their preferred foot forward on a mark 0.3 m before the start gate, and sprinted maximally through timing gates (Brower Timing System, Salt Lake City, UT, USA) set up at 0 m (start), 5 m, 10 m and 20 m (finish). Players were instructed to run as fast as possible from start to finish by running to a cone placed 2 m beyond the final gate. The fastest time of 3 trials was used for data analysis.

Multidirectional acceleration testing

Reactive and pre-planned multidirectional acceleration were both assessed via the Y-shaped agility test (19). The test has been found to be reliable (19) and to demonstrate construct validity for reactive agility in team sport players (15). Briefly, the test incorporated four pairs of timing gates (Fusion Sports, Coopers Plains, Australia) and was set up as per Lockie et al. (15). Players were required to accelerate from a standing start and to run straight ahead (7.5 m) before cutting left or right in either a pre-planned (as per pre-test instructions) or reactive (in response to a light stimulus) manner and sprinting towards a finish line (7.5 m from the middle gate) that was positioned at a 45° angle from the middle pair of timing gates.

Players began each attempt 0.3 m behind the start line and were encouraged to perform the test maximally at all times. For assessment of pre-planned multidirectional acceleration, players were informed a-priori about which direction to turn, and were encouraged to initiate the change of direction once passing through the middle timing gate. Three trials, each cutting left and right, were completed for the pre-planned multidirectional acceleration condition. The fastest trial tor each direction change was analyzed.

For reactive multi-directional acceleration, players commenced the initial stages of the test as per the pre-planned condition but were required to visually scan for a flashing light stimulus that was triggered by passing through the middle timing gate. Once identified, players cut either left or right by 45° and sprinted through the final flashing timing gate. As per the pre-planned condition, players performed six attempts but the timing-lights software was programmed such that an equal number of left and right attempts were completed in a randomized order that was unbeknown to players. The fastest trial for each turn was retained for analysis.

Statistical Analysis

All data is presented as mean ± SD and an alpha level of $P \leq 0.05$ denoted significance. Akin to the research question, seven dependent variables were identified (i.e., sprint times over 5, 10 and 20 m, and pre-planned and reactive sprint times in the left and right directions). Based on previous research, 22 predictors were initially considered as possible indicators of these dependent variables; with the intention to reduce this number by exploring the data for significant correlations. All variables were examined for normality using visual examination of histograms and Shapiro-Wilks test, whereby significance indicated non-normality. Seven variables displayed non-normal distributions and this data was bootstrapped to counter the effects of non-normality for use of parametric statistics (9). Therefore, for the first stage of the data analysis a two-tailed Pearson's correlation was used, with 1000 bootstrap samples. All predictors that indicated a moderate (i.e., $R=0.3$ upwards) and significant correlation were kept for further analysis, while all other variables were removed. Linear or multiple regressions were then used as appropriate with the remaining predictor variables and their dependent variable correlates. Significance and relative contribution of predictors was determined using a combination of standardized Beta values, t-statistics (i.e., the predictor makes a significant contribution to the model) and 95% confidence intervals (i.e., non-overlap with zero). Statements were made regarding the magnitude of change in the dependent variables resulting from a 1 SD change (increase or decrease) in the predictor variable.

RESULTS

Table 1 characterizes performance for all tests undertaken. Moderate and significant correlations with at least 1 of the 7 dependent variables (Table 2) were highlighted for 5 predictor variables (Table 3) which were retained for further scrutiny while the remaining variables were disregarded.

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For 5 m sprint time, relative PPO during bilateral CMJ explained 21% of the variance (r^2=0.21) and significant standardized beta values (P=0.020; CI=-0.002, -0.010) indicated that for every 1 SD increase in relative CMJ PPO (5.37 W·kg^{-1}), a resultant decrease of 0.03 s in 5 m sprint time was predicted.

For 10 m sprint time, isometric relative PF and relative CMJ PPO contributed a total of 44% of the variance (R^2=0.44). Standardized beta values highlighted that isometric relative PF made a near significant contribution to the model (P=0.080; CI = -0.12, 0.04) such that an increase of 5.1 N·kg^{-1} (i.e., 1 SD) would result in a 0.03 s reduction in 10 m time. However as bootstrap confidence intervals overlapped zero, the result should be interpreted with caution. Relative CMJ PPO made a significant contribution to the model (P=0.010; CI=-0.003, -0.013) whereby an increase of 5.4 W·kg^{-1} would result in a reduction of 10 m sprint time by 0.04 s.

For 20 m sprint time, the regression model indicated that isometric relative PF and relative CMJ PPO contributed a total of 55% of the variance (R^2=0.55). Standardized beta values indicated that isometric relative PF made a significant contribution to the model (P=0.050; CI=-0.12, 0.04) with a 5.1 $N \cdot kg^{-1}$ increase in force resulting in a 0.04 s decrease in 20 m sprint time. However, as before, bootstrap confidence intervals indicated that beta values for isometric relative PF encompassed zero and should therefore be interpreted cautiously. Relative CMJ PPO made a significant contribution (P=0.002; CI=-0.008, -0.018) to the model whereby an increase of 5.4 $W \cdot kg^{-1}$ would result in a 0.06 s decrease in 20 m sprint time. Bootstrap confidence intervals for relative CMJ PPO bootstrap did not encompass zero and can therefore be considered more robust.

For the reactive left condition, despite the moderate correlation observed, both contact time and RSI for the unilateral left leg DJ only explained 23% of variance (R^2=0.23). Standardized beta values indicated that for both of these variables this contribution was non-significant (P>0.05) with confidence intervals overlapping zero considerably (contact time CI = -2.10, 2.51; RSI CI = -0.65, 0.16). No further variables contributed (P>0.05) to the models for either pre-planned or reactive multidirectional acceleration.

DISCUSSION

As linear and multidirectional acceleration performance is a key indicator of success in soccer, the primary aim of this study was to isolate specific variables that predict performance in 5, 10 and 20 m linear speed tests and pre-planned and reactive multidirectional speed tests in elite soccer players. Our findings indicated that relative PPO from bilateral CMJ contributed significantly to linear sprint acceleration performances over distances of up to 20 m. Although relativized PF (derived from IMTP) significantly predicted 20 m linear sprint times, a cautious interpretation of this variable should be noted. Conversely, no indices examined throughout the IMTP, CMJ or DJ predicted multidirectional speed performance. Such information will likely assist strength and conditioning professionals in tailoring the design of testing batteries and training programs that involve elite soccer players.

Relative PPO during the bilateral CMJ contributed significantly to linear sprinting performances over 5 m, 10 m and 20 m in English Premier League soccer players. Despite the array of variables examined in this study, relative CMJ PPO was the only marker to predict performance across all distances of linear sprinting assessed. It is plausible that the contribution of bilateral relative PPO reflects established relationships between markers of strength and explosive performance (35). Previous definitions of relative strength from IMTP testing (strong: ≥38.72 ± 2.08 01 $N{\cdot}kg^{-1}$; weak: ≤30.40 ± 4.01 $N{\cdot}kg^{-1}$; (32)) would characterize the players in this study as being weak according to their relative PF values (Table 1). However, inconsistencies exist between studies concerning the inclusion of body mass in such analyses. Nevertheless, as the relationships presented here should hold true across the entire measurement range, a rationale exists for including indices of CMJ performance in testing batteries used with elite soccer players. Practitioners should also focus on the development of relative CMJ PPO as a training priority; particularly with respect to the meaningful change data reported here.

Isometric PF expressed relative to body mass, contributed significantly to 20 m linear sprint performances; although caution should be exercised due to the spanning of zero of CI data. Such findings support those observed previously using a bivariate correlational approach in elite rugby league athletes (33). Regression analyses highlighted that increases in relative PF of 5.1 $N \cdot kg^{-1}$ would predict improved sprint times by 0.03 s and 0.04 s over 10 m (1.7%) and 20 m (1.4%), respectively. To contextualize, increases in IMTP PF of approx. 3.3 $N \cdot kg^{-1}$ (from 31.6 ± 4.7 $N \cdot kg^{-1}$ to 34.9 ± 6.0 $N \cdot kg^{-1}$) have been realized after a 20 week intervention that focused on maximal strength development in a group of cyclists exhibiting comparable strength levels to the players recruited to this study (6). As match distances covered above 18 $km \cdot h^{-1}$ (18) and performance on isolated linear sprint tests (21) differentiate between elite and sub-elite players, our findings provide context about potentially meaningful changes that should be targeted in soccer players.

In agreement with West et al. (33), absolute PF did not contribute to models of linear or multidirectional sprint times. Relative strength expressed per unit of body mass, rather than absolute force output, has been proposed to influence whole-body displacement (14); albeit in the vertical direction. As linear sprint performance is dependent upon body mass acceleration rather than overcoming inertia and/or air resistance experienced during sprint cycling (31) or rapid acceleration of an Olympic bar (12), the ability to produce high levels of force relative to body mass has been proposed as being superior to absolute measures of PF (33). Indeed, where absolute isometric PF and dynamic performance indices have been found to be related, a bias towards activities that limit stretch-shortening cycle (e.g., cycling (7);

snatch (12)) actions are noted. Nevertheless, this study supports previous findings (33) and highlights the utility of isometric strength testing for characterizing dynamic performance in elite team sports players despite previous criticism (13).

Strength, power and reactive strength have been outlined as physical factors which may underpin multidirectional speed (38) but this relationship might only be observed when comparing tasks that involve limited numbers of directional changes over short distances (27). Contrary to previous studies (16, 29), none of the 22 variables examined here predicted performance in either the pre-planned or reactive multi-directional speed tasks in a population of elite soccer players. Acknowledging the potential impact of the homogeneity of participants when interpreting predictors of change of direction speed (16), it is plausible that cognitive as opposed to physical characteristics, better predict multidirectional speed tasks that incorporate a reactive component. Indeed, similarities between elite and non-elite athletes in pre-planned agility tasks diminish when a reactive stimulus is introduced (15). Likewise, the use of the light stimulus in this study may have negated a player's ability to interpret an opponent's cues that can afford anticipatory benefits in reactive tasks (1, 25, 28). To this end, it is not surprising that physical indices were unable to predict reactive agility performance in elite soccer players. Further research opportunities therefore exist to better define the aspects of cognition that underpin reactive agility performance and thus should be prioritized when training team sports athletes.

PRACTICAL APPLICATIONS

Relative CMJ PPO predicted linear sprint performances of elite soccer players over 5, 10 and 20 m distances; the only variable to demonstrate a consistent prediction of performance to each of these key performance indicators. Additionally, relative PF (derived from an IMTP) predicted 10 and 20 m linear sprint times, but the potential application of this variable should be used with caution. Notably, no indices of IMTP, CMJ or DJ performance predicted multidirectional sprint times on reactive or pre-planned agility tests. These findings highlight that CMJ and IMTP assessments (and their indices) should be considered for inclusion in the testing batteries of elite soccer players when seeking to appraise the efficacy of interventions seeking to improve linear sprint performance. Attempting to improve performance on such tests, especially those aspects related to force production relativized to body mass, will likely confer performance benefits to soccer players in linear, but not multidirectional, speed tests. Such changes may contribute to improved match performance. Further insight in to the prediction of reactive multidirectional speed tasks is required.

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FIGURE LEGENDS

Assessment	Variable	Performance

Table 1: Performance indices from IMTP, CMJ, DJ, linear and multidirectional sprinting (mean ± SD)

Table 2. Correlations (R values) of all predictor variables to measures of linear (5 m, 10 m, 20 m) and multidirectional (pre-planned and reactive) sprinting

Table 3: Correlations (R values) of those variables carried forward into regression analysis

Table 4: Unstandardized and standardized Beta values for each of the 5 regression models

Isometric mid-thigh pull (IMTP)	PF (N)	2361.9 ± 336.7
	Relative PF ($N \cdot kg^{-1}$)	30.41 ± 4.91
	Peak RFD ($N \cdot s^{-1}$)	15578.7 ± 7559.6
	F100 (N)	755.1 ± 332.4
	Relative F100 ($N \cdot kg^{-1}$)	9.8 ± 4.3
Countermovement jump (CMJ)	Bilateral jump height (m)	0.39 ± 0.04
	Bilateral PPO (W)	4229.1 ± 602.9
	Bilateral relative PPO ($W \cdot kg^{-1}$)	54.5 ± 5.3
	Unilateral left leg jump height (m)	0.21 ± 0.03
	Unilateral right leg jump height (m)	0.22 ± 0.03
	Unilateral asymmetry (m)	0.01 ± 0.03
Drop jump (DJ)	Bilateral contact time (ms)	204.2 ± 4.3
	Bilateral jump height (m)	0.30 ± 0.05
	Bilateral stiffness	27.4 ± 12.4
	Bilateral RSI	2.50 ± 0.47
	Unilateral left leg contact time (ms)	275.8 ± 4.3
	Unilateral left leg jump height (m)	0.17 ± 0.04
	Unilateral left leg RSI	1.35 ± 0.23
	Unilateral right leg contact time (ms)	272.3 ± 4.5
	Unilateral right leg jump height (m)	0.17 ± 0.04
	Unilateral right leg RSI	1.38 ± 0.25
	Unilateral asymmetry (m)	0.00 ± 0.02
Linear sprinting	5 m (s)	1.02 ± 0.07
	10 m (s)	1.72 ± 0.09
	20 m (s)	2.94 ± 0.11
Multidirectional sprinting	Pre-planned; left (s)	2.94 ± 0.24
	Pre-planned; right (s)	2.92 ± 0.10
	Reactive; left (s)	3.61 ± 0.14
	Reactive; right (s)	3.63 ± 0.15

Table 1: Performance indices from IMTP, CMJ, DJ, linear and multidirectional sprinting (mean ± SD)

IMTP: Isometric mid-thigh pull, CMJ: Countermovement jump, DJ: Drop jump, PF: Peak force, PPO: Peak power, RFD: Rate of force development, F100: Force at 100 ms, RSI: Reactive strength index