IMPORTANCE OF PHYSICAL QUALITIES FOR SPEED AND CHANGE OF DIRECTION ABILITY IN ELITE FEMALE SOCCER PLAYERS.

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ABSTRACT

The purpose of this study was to determine the importance of physical qualities for speed and change of direction (CoD) ability in female soccer players. Data were collected on 10 female soccer players who were part of a professional English Women's Super League team. Player assessments included anthropometric (stature and body mass), body composition (dual-energy X-ray absorptiometry), speed (10m, 30m sprint), CoD ability (505 agility), aerobic (Yo-Yo Intermittent Recovery Test), lower-body strength (bilateral knee extensions) and power (countermovement jump [CMJ], squat jump [SJ], 30cm drop jump [DJ]) measures). The relationships between the variables were evaluated using eigenvector analysis and Pearson correlation analysis. Multiple linear regression revealed that the performance variables (10 and 20m speed, mean 505, and CoD deficit mean) can be predicted with almost 100% accuracy (i.e. adjusted R^2 > 0.999) using various combinations of the predictor variables (DJ height, CMJ height, SJ height, lean body mass). An increase of one standard deviation (SD) in DJ height was associated with reductions of -5.636 and -9.082 SD in 10 m and 20 m sprint times. A one SD increase in CMJ also results in a reduction of -3.317 and -0.922 SD respectively in mean 505 and CoD deficit mean values. This study provides comparative data for professional English female soccer players that can be used by strength and conditioning coaches when monitoring player development and assessing the effectiveness of training programmes. Findings highlight the importance of developing reactive strength to improve speed and CoD ability in female soccer players

KEY WORDS: body composition, soccer, performance, testing

INTRODUCTION

Soccer is an intense multi-directional and intermittent field sport played by both sexes. At an elite level, soccer requires high technical ability, tactical awareness, and an exceptionally high level of physical conditioning (20). The popularity and professionalism of female soccer has increased markedly in recent years. In England the creation of the Women's Super League (WSL) in 2011 has led to elite English players now being employed on either a professional or semi-professional basis (6).

During matches, elite female soccer players have been reported to cover a total distance of ~10 km, with 1.53–1.68 km at high speeds (>18 $km \cdot h^{-1}$) (6). The distance covered during high-intensity and sprinting activities are known to be the main determinants between higher and lower standards of play (15), with elite female players reported to complete 28% more high speed running and 24% greater distance sprinting compared to non-elite level players (20). Furthermore, it is the explosive actions such as sprinting, jumping, tackling and change of direction (CoD) that appear to influence the outcome of games (21). Such demands necessitate that players demonstrate a high level of athleticism (i.e. speed, power, strength, aerobic capacity). As such it is important that these physical qualities are developed through structured and progressive strength and conditioning training, in conjunction with field based technical/tactical sessions.

Despite the acknowledged importance of developing physical qualities in female soccer players and the increased professionalism of the women's game, it has previously been reported that compliance to supplementary strength and conditioning training is still a relatively new concept for players and coaches (34). This is supported by a recent statement from the Football Association (FA) who have suggested that elite English female soccer players require more '*athleticism*' (**1)** to compete at the international level. As such it has been suggested that the players should regularly undertake strength and conditioning sessions as part of their regular training schedule to improve their *athleticism*.

Strength and power have been shown to be correlated with speed and CoD ability in both male (25) and female athletes (11, 23). As such, strength and conditioning coaches often prescribe programs to improve muscular strength and power in an effort to translate these improvements into improvements in sprint and CoD ability. However, other research has suggested that measures of strength, speed and CoD are not significantly correlated for sub-elite female soccer players (32). Differences in findings between studies may be related to the level of the gender of the athlete, level of competition and testing procedures used. Findings from Vescovi and McGuigan (32) suggested that linear sprinting, agility, and vertical jumping were independent locomotor skills in high school female soccer and lacrosse players. In contrast, Nimphious et al. (23) demonstrated that strength had a very strong correlation with speed and CoD ability in elite female softball players. Given the contrasting findings in the literature and that no study has yet considered such relationships in elite senior female soccer players, further research is required to establish the relationships between strength and power with speed and CoD ability in elite female soccer players as this may have training implications.

In addition to the inconsistencies highlighted above, research has also reported that the ratio of fat to lean mass may be related to both power and speed in both male (24) and female athletes (11). As such it has been suggested that optimizing the ratio of fat and lean mass in players should also be a focus of strength and conditioning programming to facilitate an improvement in physical performance (11). However, the relationship between lean body mass and physical performance has yet to be investigated in elite female soccer players and requires further research. Such findings can be used by strength and conditioning professionals to inform programme design in order to maximise the *'athleticism'* of elite female soccer players. Therefore, the purpose of this study was to present the physical characteristics of elite female English soccer players and to investigate the relationship between lean body mass, strength and power with speed and CoD ability. It was hypothesized that there would be a relationship between lean body mass, strength, speed and CoD ability.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

To examine the relationships between the physical characteristics of elite female soccer players, subjects competing in the highest division in England (WSL1) completed assessments of anthropometric characteristics, body composition, speed, CoD ability, endurance, lower-body strength and power. All testing was carried out during one testing session at the start of the 2016 season (after an 8 week preseason training programme). To ensure the testing procedures captured maximal performance, subjects were instructed to rest for 48 hours before the testing session and to maintain normal eating and drinking habits in the hours immediately preceding testing. To minimise diurnal variations in performance and maintain consistency with training schedules, all subjects arrived at the testing facility at 0930 hours.

Subjects were randomly assigned to one of 3 groups which differed according to the physical characteristics being investigated; station 1: anthropometric and body composition, station 2: speed and CoD ability, station 3: strength and power. To prevent an order effect, each group of subjects completed each station in a random order with a 15-minute break being permitted between stations. The endurance test was completed as one large group to limit the cumulative effects of fatigue on the speed, CoD, strength and power assessments. Before active testing protocols (i.e., speed, CoD ability, strength and power) a standardised warm-up was completed at each station which included jogging, dynamic movements and sub-maximal jumps or sprints. Although all players had previously completed the same assessments at the start of pre-season in the same environment, each test was fully explained and demonstrated by the research team beforehand and subjects completed familiarisation trials for each assessment to limit any possible learning effects. Furthermore, loud verbal encouragement was provided by the research team in each of the active testing protocols and subjects were provided with immediate feedback on their performance in an attempt to optimise subsequent performance.

SUBJECTS

Ten elite female soccer players (age: 25.4 ± 7.0 years; body mass: 62.6 ± 5.1 kg, height: 167.2 ± 5.3 cm) participated in the study at the start of the 2016 season. The players regular training schedule at their club consisted of 4-5 field based training sessions per week and 1-2 gym based strength sessions. Players were aware of the research nature of the project, with all procedures clearly explained and written consent was obtained. The study was approved by the institutional ethics committee, and written consent was obtained from each subject before commencement of testing.

PROCEDURES

Anthropometry

Height was measured to the nearest 0.1 cm using a Seca stadiometer (model 2251821009, Germany) and body mass was measured to the nearest 0.1 kg using calibrated Seca Alpha (model 770, Germany) scales.

Body Composition

For all measurements, subjects wore minimal clothing, with shoes and jewellery removed. Each subject received one total body dual-energy X-ray absorptiometry (DXA) scan (Lunar iDXA, GE Medical Systems, United Kingdom) using standard or thick mode depending on body mass and stature. Subjects lay in the supine position on the scanning table with their body aligned with the central horizontal axis. Arms were positioned parallel to the body, with legs fully extended and feet secured with a canvas and Velcro support to avoid foot movement during the scan acquisition. One skilled technologist led and analysed all scans after the manufacturer's guidelines for patient positioning. The regions of interest were manually placed to enable the appropriate cuts according to the manufacturer's instructions. Scan analysis was performed using the Lunar Encore software (Version 15.0). Dependent variables of interest were total fat mass, total lean mass and percentage body fat. DXA calibration was checked and passed on a daily basis before the study and after the study using the GE Lunar calibration hydroxyapatite and epoxy resin phantom. There was no significant drift in calibration. Local precision values for our centre (in healthy adult subjects, aged 34.6 years) are CV = 0.8% for fat mass and CV = 0.5% for lean mass.

Leg Power

The assessment of jumping capability is an accepted functional measure of power in soccer players (36). Following three warm-up trials, each subject performed three maximal vertical jumps on a force platform (Kistler 9287BA; Winterthur, Switzerland) operating at 1000 Hz under three different conditions. Countermovement jumps (CMJ) were initially performed which involved a preparatory downward movement following an upright starting position (hands on hips). Subjects were instructed to jump for maximal vertical displacement with the knee flexion angle at the bottom of the downward phase being approximately 90^{o} (8). Squat jumps (SJ) were then performed which involved a maximal vertical jump form a semi-squatting position (knee angle = 90^o approximately). Lastly, drop jumps (DJ) were performed with subjects starting from an upright position on a 40cm box. Subjects were then instructed to drop down onto the centre of the force platform landing on both feet. On landing, subjects immediately performed a jump for maximum vertical displacement while keeping hands placed on hips and landing back on the force platform (8).

The SJ provides an assessment of the concentric ability to apply force upwards whereas the CMJ and DJ provide a leg power assessment through the stretch-shortening cycle function. In line with their rationale for selection, jump height (m) and propulsive rate of force development (RFD) were calculated for the CMJ and SJ whilst jump height and reactive strength index (RSI) were calculated following the performance of the DJ using Bioware software (version 5.1.4; Kistler, Winterthur, Switzerland). Jump height was calculated using the flight time (time subjects spent airborne in each jump) method (0.5 x 9.81 x flight time^2), RFD was determined as the slope of the vertical force curve between peak force and take-off, whereas RSI was calculated by dividing the jump height in the DJ by the contact time (duration of contact during the first landing) before the jump. The best out of the 3 trials (based on jump height) was selected for statistical analysis. Between-trial reproducibility for jump height achieved during each CMJ, SJ and DJ was intraclass correlation (ICC) = 0.99 and coefficient of variation (CV) = 1.1%, ICC = 0.99 and CV = 1.2%, and ICC = 0.93 and CV = 3.2% respectively. The within-session reproducibility for the RSI was ICC = 0.93 and CV = 3.5%.

Leg Strength

The maximal bilateral isometric force and explosive force generating characteristics of the knee extensor muscles were measured using a custom-made isometric device consisting of a customised leg extension machine (GLCE365, Body Soild UK), which was connected to a force platform (Kistler 9253B22, 1000 Hz) via a chain. Subjects were seated on the leg extension machine (hip angle = 110°, knee angle = 108.30 ± 2.31°) and then stabilized at the pelvis by a belt to isolate the movements to the lower extremity and avoid any assistance from the trunk muscles. Three maximum voluntary contractions (MVC) were performed by each individual with subjects being instructed to react to an auditory signal by attempting to extend their lower limbs as forcefully as possible and to maintain the maximal force for 3 s. The force platform measured the vertical and the anterior-posterior force production and consequently the MVC relative peak force (PF) for the leg extensors was defined as the highest value of the resultant force recorded during the MVC and was determined using Kistler Bioware software (version 5.1.4; Kistler, Winterthur, Switzerland). To account for subject's explosive force generating capabilities the MVC's were further analysed for peak rate of force development (MVC RFD), this was conducted for the best trial (based on the highest PF value). In line with previous research (7), MVC RFD was determined as the steepest portion of the resultant force-time curve from the onset of the MVC to the instance in which PF was reached. Between-trial reproducibility for was CV = 1.2% and ICC = 0.924 for PF and CV = 3.0% and ICC = 0.875 for MVC RFD.

Speed

Sprinting speed was assessed over 10, 20, and 30m using timing gates (Brower Timing Systems, IR Emit, Draper, UT, USA). Subjects started 0.5 m behind the initial timing gate and were instructed to set off in their own time and run maximally past the 30 m timing gate. In line with the other assessments, each subject had 3 attempts and trials were separated by a 2–3 minutes rest period to allow full recovery between sprint attempts. Times were recorded to the nearest 0.01 seconds with the fastest velocity of the 3 attempts used for the sprint score. ICC and CVs for 10, 20, 30 m sprint times were ICC = 0.95 and CV = 1.4%, ICC = 0.92 and CV = 1.3%, ICC = 0.90 and CV = 1.5%.

Change of Direction

Given the multi-directional nature of soccer (21), the 505 test was utilised as a measure of change of direction ability. Subjects were positioned 15 m from a turning point and timing gates were placed 10 m from the start point and 5 m from the turn point. The players accelerated from the start, through the timing gates, turning 180^0 at the 15 m mark and sprinted back through the timing gates. Subjects completed 3 alternate trials, turning off their left and right foot, separated by a 2–3 minutes rest period. Only attempts whereby the subject's foot crossed the 15 m mark were recorded. Times were recorded to the nearest 0.01 seconds with the quickest of the 3 attempts used.

While the 505 test has been identified as a reliable test (26), it has been suggested that using the total time to complete the test as a measure of CoD may not necessarily accurately represent the CoD ability of a player (22). Thus, a player who is fast linearly may still perform well in a CoD test, as their sprinting ability could mask any deficiencies in CoD ability (22). Therefore, in addition to reporting total time for the 505 test, which is consistent with previous studies in soccer (6), the CoD deficit was calculated for each player, using the following equation;

COD Deficit = mean 505 time – mean 10 m time (22).

The CoD deficit for both sides was calculated as the difference between average 505 time and 10 m time (22). ICC and CV for the 505 test were ICC = 0.99, CV = 2.2%.

STATISTICAL ANALYSES

Descriptive statistics (mean ± standard deviation [SD] and range) were initially calculated for all dependent variables. After data were assessed for heteroscedasticity, relationships between the dependent variables were evaluated using eigenvector analysis and were supplemented by Pearson product-moment correlations (with two-tailed significance test). r-values interpreted as 0.1-0.29 = small, 0.3-0.49 = moderate, 0.5- 0.69 = large, and 0.7-0.9 = very large (3).

Statistical analyses of data were performed using 'in-house' algorithms written in 'R' (open source statistical software) and Matlab (Mathworks, Natick, USA). For all tests, *p* values <0.05 were deemed to be significant. Eigenvector analysis was used because it enabled the data to be orthogonalized, thus allowing the vectors associated with the measured variables to be plotted in the eigenspace. In order to perform the eigenvector analysis we created a (m ´ n) matrix, *X*, containing the entire dataset with all the subjects aggregated together. The columns of the *X* matrix comprised the variables, which were mean-adjusted and standardized to unit variance, while the rows represented the subjects included in the analysis. We then computed the covariance matrix, *C*, as follows:

$$C = X^T.X \qquad (1)$$

After this, we performed eigen-decomposition of the covariance matrix to compute the matrix of eigenvalues, *D*, and the matrix of eigenvectors, *V*, as follows:

$$C = V.D.V^T \qquad (2)$$

The first, second and third eigenvectors, which accounted for the greatest amount of variance in the data, were then used to produce a compass plot of the vectors associated with respective measured variables. Having evaluated the relationships between the variables, multiple linear regression (MLR) analysis was then performed to assess the degree to which lean body mass, strength and power indicators could be predicted using speed, agility and anthropometric measures. For each output (dependent) variable all the possible combinations of the predictor variables were assessed, with the lowest Akaike information criterion (AIC) used to select the strongest model. In order to validate the MLR models and assess their general predictive applicability, we performed 'leave one out' (LOO) cross-validation on the selected models. LOO cross-validation involves using (n-1) observations (where n is the number of observations in the dataset) as the training set and the remaining observation for validation purposes. In order to validate the model, this process is repeated n times with each observation used in turn for validation purposes (10)

RESULTS

The descriptive statistics for the measured variables are reported in Table 1.

****TABLE 1 NEAR HERE****

Eigenvector analysis was conducted to assess the collinearity between variables (Figure 1). The eigenvector shows a compass plot of the vectors for the respective measured variables in the eigenspace. Collectively, the first three eigenvectors accounted for 80.1% of the variance in the data, with the first and second eigenvectors accounting for 33.7% and 31.6% of the variance respectively, while the third eigenvector only accounted for 14.8%. From Figure 1 it can be seen that considerable multi-collinearity exists within the predictor and outcome variables. This is reflected by the strong correlations between the variables CoD deficit mean, mean 505 and the variables 10 and 20 m speed (e.g. CoD deficit mean and mean 505, r =

0.856, p=0.002 10 m speed and 20 m speed, r = 0.862, p = 0.001; CoD deficit mean and 10m speed, r = -0.755, p = 0.012; and CoD deficit mean and 20m speed, r = -0.833, p = 0.003). Similarly, considerable collinearity is also observed between the variables SJ and CMJ performance (both in height and RFD) (e.g. SJ height and CMJ height, r = 0.916, p<0.001; SJ RFD and CMJ RFD, r = 0.591, p = 0.069; SJ height and SJ RFD, r = -0.751, p = 0.012; and CMJ height and CMJ RFD, r = -0.756, p = 0.011). A strong correlation is also observed between DJ height and CMJ height (r = 0.944, p < 0.001).

A moderately strong negative relationship was observed between CoD deficit mean and MVC relative PF (r = -0.557, p = 0.095), but this was not significant. The correlations between DXA derived body composition (total body fat and lean mass) and performance measures were also explored. For the most part these correlations did not reach significance, despite some moderately strong negative correlations relating to total body fat and 10 m speed (r = -0.542, p=0.106) and 20 m speed (r = -0.562, p = 0.091). However, it is likely that these relationships may not have been significant due to the sample size and if a larger sample size had been used, such relationships may have reached significance.

**FIGURE 1 ABOUT HERE **

The results of the multiple linear regression analysis are presented in Table 2. These reveal that the performance variables 10 m speed, 20 m speed, mean 505, and CoD deficit mean can be predicted with almost 100% accuracy (i.e. $R^2 \geq 0.999$) using various combinations of the predictor variables. Furthermore, the very high coefficient of determination (R^2) values achieved, are supported by strong cross-validation results (i.e. $R^2 \geq 0.716$), suggesting that the MLR models have good predictive accuracy and they are general applicable. It can be seen that the variable DJ height is particularly influential, with an increase of one SD in DJ height being associated with reductions of -5.636 and -9.082 SD in 10 m and 20 m sprint times. CMJ height was also influential, with an increase of one SD resulting in a reduction of -3.317 and -0.922 SD respectively in mean 505 and CoD deficit mean values. SJ height was also highly influential in predicting CoD deficit mean, having a beta value of -13.010.

TABLE 2 NEAR HERE*

DISCUSSION

The purpose of this study was to present the physical characteristics of elite female soccer players in England and to investigate the relationship between lean body mass, strength and power with speed and CoD ability. Findings suggest that sprint performance is related to jump assessments that include a fast stretch shortening cycle (SSC) such as a drop jump, while CoD ability is related jump assessments that require a slower SSC, as this is more reflective of the muscle actions during sprinting and changing direction respectively. These data can be used as by practitioners as reference data when evaluating the performance of senior female soccer players and to help inform the design of strength and conditioning programmes for female soccer players, in order to improve their '*athleticism*'.

Physical Characteristics

Body mass and stature of the players in this study were within the range previously reported in the literature for female elite soccer players (57 – 65 kg; 161 – 170 cm) (6). In contrast, percentage body fat was higher than the given range previously reported for elite players (14.6 – 20.1%; (6). The difference may be due to the previous method used to assess percentage body fat (i.e., estimation from sum of skin fold analysis). This is the first study to report body composition using DXA in female soccer players, which has previously been shown to be more valid (16).

10 and 20 m sprint times from elite English female players in this study were faster than previously reported for elite Australian players (1.91 ± 0.04 and 3.26 ± 0.06 s) (29). A possible explanation for the observed differences in speed may be due to the increased professionalism of the women's game in England, whereby players now undertake full time training and structured strength and conditioning programmes. It has been proposed that sprint performance can distinguish between standards of competition (9 31) with selected players from trials for the American professional soccer league being between 0.5 and 0.8 $km \cdot h^{-1}$ faster than their non-selected equivalents (31). Similar findings were reported during an Australian talent identification project, with selected players recording faster times over 5, 10 and 20 m, respectively than the non-selected players (9). Thus, this study provides speed data for elite female soccer players in England that practitioners can use for comparative purposes, although further research will be required before comparisons can be made between competitive standards.

To the author's knowledge, this is the first study to use biomechanical set-ups and equipment (force platforms) to investigate muscular strength and power in female soccer players. Previous studies have characterized the power performance of female soccer players at domestic (27) and senior levels (2) however, comparisons between studies are difficult due to the different protocols (SJ, CMJ, DJ), equipment adopted (jump mat, Optojump) and the recent increases in professionalism in the women's game. English players from this study had similar CMJ height to Italian international players (31.6 ± 4.0 cm) (2), although the different methodologies (i.e. force plate vs. Optojump) should be acknowledged.

Comparing the performances of different jump variations can provide strength and conditioning coaches with information regarding the effectiveness of a players SSC utilization which may be particularly important given the role of the SSC in many soccer-related activities (e.g. sprinting, jumping, CoD). Whilst CMJ performance is frequently used to assess lower body power production for training monitoring and talent identification purposes (2), it must be noted that previous studies into female soccer have reported a narrow range of jump variations (6). The present study therefore provides comparative data for vertical jump variations in elite senior female soccer players from which other metrics of SSC utilization could be calculated.

Despite the fact that CoD performance can distinguish between playing level in male soccer players (28), there is limited research available on the CoD ability of female soccer players. Of the limited data available, comparisons between studies are further limited by the different methodologies used to assess CoD ability (i.e. T-test, illinois agility, 505). In comparison to female team sport athletes (2.63 ± 0.10 s; 17), players in this study had faster CoD times. While the 505 test has been identified as a reliable test (26), it has been suggested that using the total time to complete the test as a measure of CoD may not necessarily accurately represent the CoD ability of a player (22). Thus, a player who is fast linearly may still perform well in a CoD test, as their sprinting ability could mask any deficiencies in CoD ability (22). Therefore, findings of this study provide the first comparative data for the CoD deficit for elite female soccer players.

Relationships between laboratory and field-based testing

The findings of this study demonstrate very strong relationships between lower body strength and power and total body fat, with speed and CoD ability. 10 m, 20 m sprint times, were predicted with almost 100% accuracy and 505 mean and CoD deficit were predicted with 100% accuracy using models containing CMJ, SJ, DJ, MVC relative PF and total body lean mass. Such findings are consistent with previous research reporting the importance of maximal strength (23) and reactive strength (37) for CoD performance in female athletes. Young et al. (37) demonstrated that reactive strength (from a DJ) demonstrated the strongest relationship with CoD ($r = -0.54$; $p < 0.05$). Since reactive strength may be closely linked to vertical stiffness (18), the present findings demonstrate the need to consider such physical qualities when designing strength and conditioning programmes aimed at optimising on-field activities. From a strength perspective, Nimphius and colleagues (23) found strong to very strong relationships ($r = -0.50$ to -0.75) between relative maximal dynamic strength and 505 CoD performance of the dominant leg in female softball athletes. Whilst the present findings demonstrate this relationship in female soccer players, it must be noted that the use of an isometric strength assessment in this investigation did not impact on the relationship between strength and CoD performance. Although there are numerous studies which report weak relationships between isometric and dynamic activities (35, 37), the present findings highlight that the bilateral isometric strength testing protocol utilised in this study demonstrates adequate specificity to predict differences in CoD performance. Such information may be of use to practitioners when designing testing batteries for monitoring/talent identification purposes in female soccer players.

Eigenvector analysis revealed collinearity between some variables (Figure 1), such as CMJ RFD and SJ RFD. Whilst the similarity between some variables may be used to question the inclusion of all these measures within a testing battery, practitioners should look beyond their apparent similarity and consider that slight variations of similar assessments (e.g. CMJ, SJ) reveal important information regarding an individuals neuromuscular capabilities (e.g. SSC utilization). The findings of this study suggest that an improvement of 1 SD in DJ height would result in an improvement in 10 m speed by approximately 5 SDs (-0.34 s) and 20 m speed by approximately 9 SDs (-0.64 s). DJ appears not only a key test when quantifying the speed qualities of female soccer players, but findings suggest it may also a useful exercise to develop these specific qualities, given the relationship with 10 and 20 m sprint performance. The observed relationship between DJ and sprint performance in this cohort is likely to be due to the similarities in muscle actions (5). A DJ is a method of assessing reactive strength, which is important for sprint ability. Furthermore, both the DJ exercise and sprinting include a relatively small leg extension range of motion, relatively short contact time and muscle power involving stretch-shortening cycle actions (37), which is likely to account for the strong relationship.

Although the results of the regression analysis are informative, it is important to treat them with caution. Theoretically, based on the findings of this study, improving DJ height by 1SD would result in 10 m time beyond the time achieved by anyone within the study group. For example a 1SD improvement from the mean DJ would in theory result in a 10 m time of 1.53 s based on the trend line, which is beyond the 10 m sprint time performance of any of the subjects within this group (range: 1.79-1.96s). As such, it is highly likely that a sprint ceiling exists and this should be taken into consideration when interpreting the linear regression models and attempting to predict performance using purely physical qualities (e.g., DJ height).

In contrast to the positive association between DJ height and 10m sprint time, the study suggests that an improvement in SJ height by 1 SD, increases 10 m sprint time (i.e., athletes are slower) by approximately 5 SDs (0.34 s) and an improvement by 1SD in CMJ jump height appears to increase 20 m time by approximately 3SD (0.19) in this cohort. While a number of previous studies have reported CMJ and SJ height to be a predictor of sprint speed (4), it has also been shown by some researchers that these jumps (DJ, CMJ, SJ) assess unique explosive lower limb power qualities. Nimphius et al. (23) also reported a positive relationship between CMJ height and sprint time in female softball players. In terms of the interrelationship between DJ and CMJ measures (r = 0.69-0.73) and the associated coefficients of determination (R^2 = 47.6-53.2%), there appears a great deal of unexplained variance between the tests, suggesting that the jumps to some degree measure different explosive qualities (5). CMJ is reported to be representative of a slow (>250 milliseconds) SSC performance and DJ is reported to be representative of a fast (< 250 milliseconds) SSC performance (5). Furthermore, the SJ test represents an athletes ability to concentrically overcome the inertia of their body mass and does not include the eccentric component of the jump (19). Therefore, given that sprinting may be more dependent on reactive strength and includes both an eccentric and concentric component, this may explain why SJ or CMJ performance were not associated with improvements in 10 m and 20 m speed in this cohort. Given the positive association observed between speed and DJ height, the findings suggest that the DJ replicates more closely the movement profile of sprinting (12). As such, when looking to develop speed, exercises that elicit fast SSC performance (i.e. plyometric training) may be the most appropriate training method for strength and conditioning coaches to utilise. Furthermore, the DJ may provide a more appropriate monitoring and training tool rather than the CMJ for practitioners to use when looking to develop speed of female soccer players.

The findings of the study suggest that an improvement in SJ and CMJ height of 1SD appears to improve 505 time and CoD deficit by approximately 3 and 13 SDs, respectively, whereas improvements in DJ height of 1SD increase 505 and COD deficit time by 7 and 12 SDs. This is consistent with some findings of previous research (36) but contradicts others (4). As previously highlighted, SJ and CMJ are regarded as slow SSC exercises (5). Therefore, due to the need for longer ground contact times when changing direction versus sprinting, SJ and CMJ performance are more specific to the demands of CoD ability, in comparison to the fast SSC that occurs during a DJ. Furthermore, the lack of relationship between improvements in DJ height and CoD ability may also be explained by the complexity of the movement. CoD ability is likely influenced more by motor control factors and technical proficiency than the strength qualities of the muscle (37).

It must be acknowledged that a major limitation of this study was the small sample size. The inherent nature of working with elite players limits subject numbers and this should be taken in to consideration when interpreting the findings of this study. Aware of this limitation, we endeavoured to compensate for the small study size by cross-validating the results for the respective MLR models. This revealed that all the models were good predictors of athletic performance, suggesting that they were robust and that they exhibited good general applicability. Notwithstanding this, it is recommended that future studies should seek to recruit a larger, more heterogeneous, sample of players in order to confirm or refute our findings.

In conclusion, findings of this study suggest that, in elite female soccer players, determinants of speed, and CoD ability are different components of athletic ability that rely on different strength qualities. While the findings highlight the importance of developing strength in female soccer players to improve speed and CoD ability, the findings also suggest that focusing on only one part of the force-velocity curve (i.e. max strength or reactive strength) may not lead to greatest improvements in performance when looking to developing speed and CoD ability in female soccer players. Sprinting performance appears to be related to fast SSC, as assessed using jump assessments such as a DJ, while CoD ability is related to slower SSC as assessed by CMJ and SJ. Such assessments are more reflective of the muscle actions that occur during sprinting and CoD respectively. Practitioners need to be aware of these differences when selecting a testing battery.

PRACTICAL APPLICATIONS

Anthropometric and fitness characteristics of players have been shown to be important attributes for soccer performance. This study provides comparative data for professional English female soccer players that can be used by strength and conditioning coaches when monitoring players' development and assessing the effectiveness of training programmes.

Findings of this study highlight the importance of developing strength to improve speed and CoD ability in female players. Developing strength will also lead to increases in lean body mass, which may also help improve the '*athleticism*' of players. Findings of this study suggest that plyometric training methods that target reactive strength (fast SSC) qualities may be beneficial to develop 10 and 20 m speed in female soccer players. To develop CoD ability, strength and conditioning coaches should be aware that a more holistic approach to development may be required that considers both the strength and power qualities of the lower limbs as well as the specific movement technique of the athlete.

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REFERENCES

1. Campbell, S. English female footballers 'need more athleticism' say FA's Baroness Campbell. Retrieved from: http://www.bbc.co.uk/sport/football/3928507. 2017
2. Castagna, C, and Castellini, E. Vertical jump performance in Italian male and female national teams soccer players. J Strength Cond Res 27(4): 1156–61, 2013
3. Cohen J. Statistical power analysis for the behavioral sciences. Routledge Academic, 2013.
4. Comfort, P, Stewart, A, Bloom, L, and Clarkson, B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. J Strength Cond Res *28*: 173-177, 2014.
5. Cronin, JB, and Hansen, KT. Strength and power predictors of sports speed. J Strength Cond Res *19*: 349-357, 2005.
6. Datson, N, Hulton, A, Andersson, H, Lewis, T, Weston, M, Drust, B, and Gregson, W. Applied physiology of female soccer: an update. J Sport Med, 44: 1225-1240, 2014.
7. Haff, G, Carlock, J, Hartman, M, Kilgore, J, Kawamori, N, Jackson, JR, Morris, RT, Sands, WA, and Stone, MH. Force-time curve characteristics of dynamic and isometric muscle actions of elite women Olympic weightlifters. J Strength Cond Res 19: 741-748, 2005.
8. Herrington, L. Knee valgus angle during landing tasks in female volleyball and basketball players. J Strength Cond Res 25: 262-266, 2011.
9. Hoare, D, and Warr, CR. Talent identification and women's soccer: An Australian experience. J Sports Sci 18: 751–758, 2000.
10. James, G, Witten, D, Hastie, T, Tibshirani, R. An introduction to statistical learning with applications in R. Chapter 5 Cross-validation. Springer, New York. 2013
11. Jones, B, Emmonds, S, Hind, K, Nicholson, G, Rutherford, Z, and Till, K. Physical Qualities of International Female Rugby League Players by Playing Position. J Strength Cond Res, 30: 1333-1340, 2016.
12. Kale, M, Asçi, A, Bayrak, C, and Açikada, C. Relationships among jumping performances and sprint parameters during maximum speed phase in sprinters. J Strength Cond Res, 23: 2272-2279, 2009.

13. Krustrup, P, Mohr, M, Amstrup, T, Rysgaard, T, Johansen, J, Steensberg, A, Pedersen, PK, and Bangsbo, J. The yo-yo intermittent recovery test: physiological response, reliability, and validity. Med Sci Sport Exerc, *35*: 697-705, 2003.
14. Krustrup, P, Zebis, M, Jensen, JM, and Mohr, M. Game-induced fatigue patterns in elite female soccer. J Strength Cond Res 24: 437-441, 2010.
15. Le Gall, F, Carling, C, Williams, M, and Reilly, T. Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. J Sci Med Sport, 13: 90-95, 2010.
16. Lee, SY, and Gallagher, D. Assessment methods in human body composition. Current opinion in clinical nutrition and metabolic care, 11: 566, 2008.
17. Lockie, RG, Schultz, AB, Callaghan, SJ, Jordan, CA, Luczo, TM, and Jeffriess, MD. A preliminary investigation into the relationship between functional movement screen scores and athletic physical performance in female team sport athletes. Biol Sport, 32: 41, 2015.
18. Maloney, SJ, Richards, J, Nixon, DG, Harvey, LJ, and Fletcher, IM. Do stiffness and asymmetries predict change of direction performance? J Sports Sci, 1-10, 2016.
19. McFarland, IT, Dawes, JJ, Elder, CL, and Lockie, RG. Relationship of two vertical jumping tests to sprint and change of direction speed among male and female collegiate soccer players. Sports, 4: 11, 2016.
20. Mohr, M, Krustrup, P, Andersson, H, Kirkendal, D, and Bangsbo, J. Match activities of elite women soccer players at different performance levels. J Strength Cond Res, 22: 341-349, 2008.
21. Mujika, I, Santisteban, J, Impellizzeri, FM, et al. Fitness determinants of success in men's and women's football. J Sports Sci 27(2): 107–14, 2009.
22. Nimphius, S, Callaghan, SJ, Sptieri, T, and Lockie, RG. Change of direction deficit: A more isolated measure of change of direction performance than total 505 time. J Strength Cond Res 11: 3024-3032, 2016.
23. Nimphius, S, Mcguigan, MR, and Newton, RU. Relationship between strength, power, speed, and change of direction performance of female softball players. J Strength Cond Res, 24: 885-895, 2010.
24. Potteiger, JA, Smith, DL, Maier ML, & Foster, TS. Relationship between body composition, leg strength, anaerobic power, and on-ice skating performance in division I men's hockey athletes. J Strength Cond Res 24: 1755-1762, 2010.

25. Russell, M, Shearer D, Cook, C, and Kilduff, L. Predictors Of Linear And Multidirectional Acceleration In Elite Soccer Players. J Strength Cond Res, 2017.
26. Sayers, MG. Influence of test distance on change of direction speed test results. J Strength Cond Res, 29: 2412-2416, 2015.
27. Sedano, S, Vaeyens, R, Philippaerts, RM, Redondo, JC, and Cuadrado, G. Anthropometric and anaerobic fitness profile of elite and non-elite female soccer players. J Sports Med Phys Fit 49: 387–94, 2009.
28. Suchomel TJ, Nimphius, S, and Stone, MH. The importance of muscular strength in athletic performance. J Sports Med 46: 1419-1449, 2016.
29. Tumilty, D, and Darby, S. Physiological characteristics of Australian female soccer players. J Sports Sci 10: 145, 1992.
30. Vescovi, JD, Rupf, R, Brown, TD, and Marques, MC. Physical performance characteristics of high-level female soccer players 12–21 years of age. Scand J Med Sci Sport 21: 670-678, 2011.
31. Vescovi, JD. Sprint speed characteristics of high-level American female soccer players: Female Athletes in Motion (FAiM) Study. J Sci Med Sport 15: 474–8, 2012.
32. Vescovi, JD, and McGuigan, MR. Relationships between sprinting, agility, and jump ability in female athletes. J Sport Sci 26: 97–107, 2008
33. Wisloff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 38: 285– 288, 2004,
34. Wight, 2016 Wright, MD, and Laas, MM. Strength training and metabolic conditioning for female youth and adolescent soccer players. J Strength Cond Res, *38*: 96-104, 2016.
35. Wilson, GJ, Lyttle, AD, Ostrowski, KJ, and Murphy, AJ. Assessing dynamic performance: a comparison of rate of force development tests. J Strength Cond Res 9(3): 176-181, 1995.
36. Young, W., Hawken, M., & McDonald, L. Relationship between speed, agility and strength qualities in Australian Rules football. Strength Cond Coach, 4, 3-6, 1996.
37. Young, WB, James, R, and Montgomery, I. Is muscle power related to running speed with changed of direction? J Sport Med Phys Fit, 42: 282, 2002.

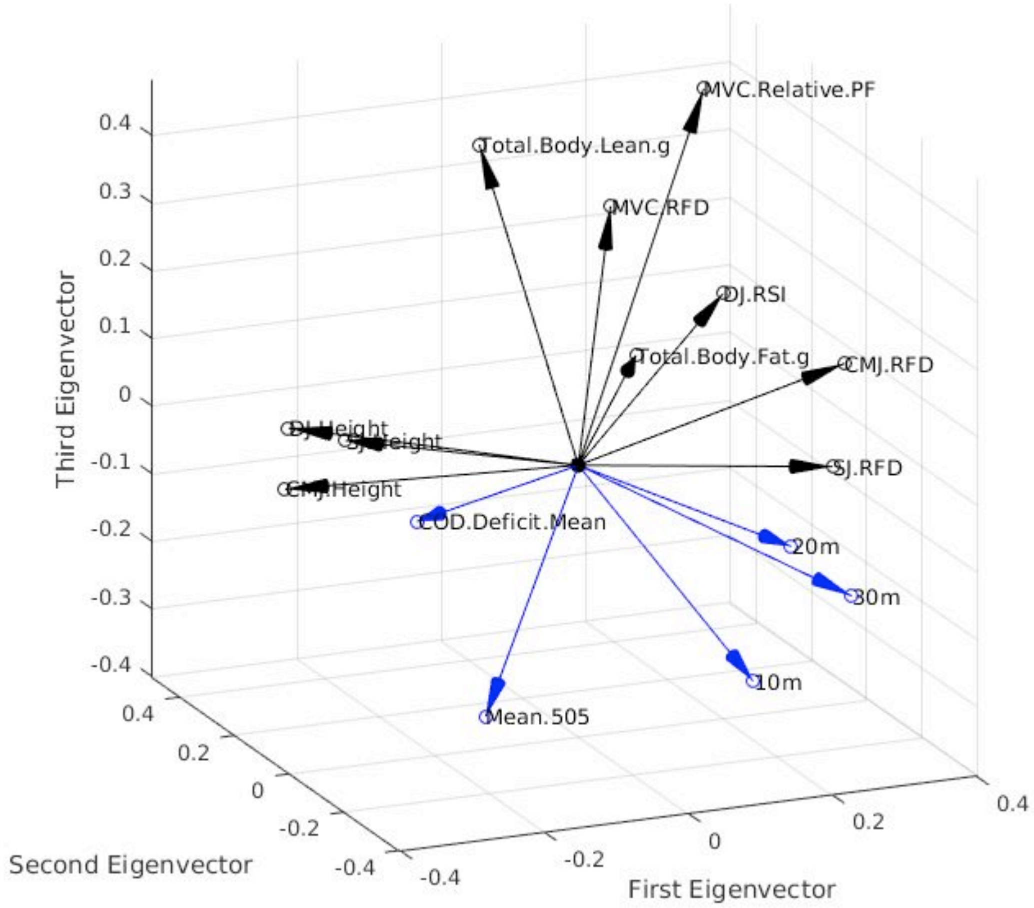

Figure 1. Compass plot of the first, second and third eigenvector loadings relating to the respective predictor (black) and outcome (blue) variables.

Table 1: Anthropometric and physical characteristics of English elite female soccer players.

Variable	Mean	Standard Deviation	Range
10m (s)	1.87	0.06	1.79 – 1.96
20m (s)	3.21	0.07	3.15 – 3.39
30m (s)	4.52	0.10	4.40 – 4.73
Mean 505	2.38	0.07	2.30 – 2.50
COD-Deficit mean (s)	0.51	0.10	0.40 – 0.69
CMJ Height (m)	0.31	0.04	0.23 – 0.36
CMJ RFD (N/s)	-13450.8	2431.6	-17129 - -9350
SJ Height (m)	0.28	0.04	0.20 – 0.35
SJ RFD (N/s)	-13264.7	2361.1	-17478 – -10333
DJ Height (m)	0.30	0.04	0.22 – 0.34
DJ RSI	1.17	0.14	0.92 – 1.41
MVC Relative PF (x BW)	1.54	0.22	1.27 - 1.93
MVC RFD (N/s)	3887.3	2455.3	2000 – 9264
Total Body Fat (g)	12897.0	2287.8	9085 - 15874
Total Body Lean (g)	46228.9	4484.6	37858 - 53474
Total Body Fat (%)	21.31	3.87	15.6-28.0

Table 2: Results of the linear regression analysis

Dependent Variable	Independent Variables	Coefficients (b)	Standardized Coefficients (Beta)	Coefficient Significance (p value)	Model Adjusted R^2 value (95% CI) [*p* value]	Cross-validation R^2 value (95% CI)	AIC
10m	Intercept	1.822	-	0.005	0.999 (0.999-1.000) [0.023]	0.961 (0.934-0.988)	-100.9
	CMJ Height	0.998	1.422	0.078			
	CMJ RFD	-8.435e-06	-1.995e-10	0.067			
	SJ Height	3.976	5.738	0.016			
	SJ RFD	3.717e-05	9.053e-10	0.011			
	DJ Height	-3.933	-5.636	0.016			
	DJ RSI	0.320	0.128	0.012			
	MVC Relative PF	-0.292	-0.078	0.020			
	Total Body Lean	5.923e-06	7.594e-11	0.028			
20m	Intercept	3.335	-	0.005	0.999 (0.999-1.000) [0.021]	0.716 (0.546-0.886)	-97.7
	CMJ Height	1.504	2.736	0.044			
	CMJ RFD	-7.343e-05	-2.215e-09	0.018			
	SJ RFD	3.911e-05	1.215e-09	0.011			
	DJ Height	-4.967	-9.082	0.023			
	MVC Relative PF	0.469	0.160	0.018			
	MVC RFD	-3.139e-05	-9.381e-10	0.018			
	Total Body Fat	-4.550e-05	-1.459e-09	0.007			
	Total Body Lean	1.019e-05	1.667e-10	0.019			
Mean 505	Intercept	3.406	-	<0.001	1.000 (1.000-1.000) [0.002]	0.990 (0.983-0.997)	-145.2
	CMJ Height	-1.914	-3.317	0.003			
	CMJ RFD	6.887e-05	1.980e-09	0.002			
	SJ RFD	-2.598e-05	-7.693e-10	0.002			
	DJ Height	4.241	7.390	0.003			
	MVC Relative PF	-0.710	-0.231	0.001			
	MVC RFD	3.827e-05	1.090e-09	0.001			
	Total Body Fat	2.068e-05	6.319e-10	0.002			
	Total Body Lean	-1.041e-05	-1.624e-10	0.002			
COD Deficit Mean	Intercept	1.594	-	0.001	1.000 (1.000-1.000) [0.004]	0.999 (0.999-1.000)	-124.0
	CMJ Height	-0.532	-0.922	0.031			
	CMJ RFD	4.538e-05	1.305e-09	0.004			
	SJ Height	-7.414	-13.010	0.002			
	SJ RFD	-6.650e-05	-1.969e-09	0.002			
	DJ Height	7.037	12.264	0.003			
	DJ RSI	-0.438	-0.214	0.003			
	MVC RFD	2.352e-05	6.699e-10	0.004			
	Total Body Lean	-1.752e-05	-2.731e-10	0.003			